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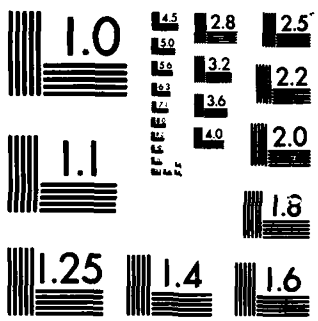

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Minuteman Stage III Operational Surveillance Program

Seven-Year Testing Bondline Aging Study

December 1985

MORTON THIOKOL, INC.
Wasatch Operations
P.O. Box 524, Brigham City, Utah 84302 (801)863-3511

MINUTEMAN STAGE III OPERATIONAL SURVEILLANCE PROGRAM

SEVEN-YEAR TESTING
BONDLINE AGING STUDY

DECEMBER 1985

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PREPARED BY:

Michael R. Knight
Mechanical Properties Section

APPROVED BY:

Dr. R. D. Taylor, Supervisor
Mechanical Properties Section

Leroy C. Porter, Program Manager
Minuteman Programs

Dr. R. L. Carpenter, Manager
Propellant Development Department

MORTON THIOKOL, INC./WASATCH OPERATIONS
P. O. BOX 524
BRIGHAM CITY, UTAH 84302

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1.0 INTRODUCTION

This report contains results of the yearly material properties testing of Stage III motor segments in the 12-year bondline aging study. Also reported are the results obtained in the continued testing/monitoring of Motor TC 30024 (LRSLA Simulated Aging Test Motor No. 3), as are the second-year results of tests upon the bondline materials and propellant obtained from dissected Stage III segments of Motor TC 30072. Tests on the excise samples from motors TOP-19, -20, and -21 were not performed this year because the test specimens were not delivered. Figure 1 is a general summary of the tests to be performed.

The testing reported herein was performed during the period of 1 December 1984 through 30 September 1985. The testing of segments from motors TC 30005, TC 30019, and TC 30033 took place during August and September 1985. Second-year tests of the motor TC 30072 segments were conducted in the June-September 1985 time period. The effort was accomplished in accordance with TWR-20946, "Test Plan, Minuteman Stage III Operational Surveillance Program," October 1978, and its Addendum No. 1, dated January 1981, and Addendum No. 2, May 1983.

1.1 Twelve-Year Bondline Aging Study

This phase of the Minuteman Stage III Surveillance Program uses segments removed from three in-process reject motors: TC 30005, TC 30019, and TC 30033. All three motors were cast in 1971 and were rejected due to apex voids. Segments maintained at silo conditions are being used to track bondline aging of Stage III motors with testing of material properties being performed at one-year intervals to 1990. This report contains the data from the seven-year aging test interval. The actual time between baseline or zero-time testing and this test period is about 78 months.

1.2 Testing/Monitoring of Motor TC 30024

Motor TC 30024 was earlier conditioned for 16 months at 110°F and 80 percent RH as LRSLA Simulated Aging Test Motor No. 3, wherein the liner at the forward flap was brought to a fully degraded condition. Between the end of conditioning and August 1981, a period of 23 months, motor TC 30024 was kept in storage in a horizontal position at approximately 70°F and ambient RH. Since then, it has been in vertical storage, aft end down, at 70°F and 50 percent RH interrupted only for brief periods to allow radiographic and visual inspection at regular intervals to monitor the existing forward and aft bondline separations and other areas of the motor. In addition, motor TC 30050 segments that accompanied this motor during the Simulated Aging Test are being tested at two-year intervals (in 1981, 1983, and 1985) to give an indication of the present material properties of motor TC 30024.

1.3 Material Properties Testing of Dissected Motor TC 30072

Motor TC 30072 was cast on 8 December 1971, spent most of its life in the operational force, and then was fully dissected by Wasatch Operations personnel during April and May 1983. Following dissection, extensive material properties testing of the propellant/liner/insulation bond system was performed on motor segments from preselected locations. The remaining motor segments will be tested at one-year intervals over the next five years. Prior to testing, the segments are being stored at nominal silo conditions. The second-year test results are reported herein, representing the motor condition at about 165 months of age.

2.0 OBJECTIVES

2.1 Twelve-Year Bondline Aging Study and Excise Sample Testing

The program objective is to provide material properties aging data at silo conditions (70 $\pm$ 5 F, 50 $\pm$ 5 percent RH) for liner bond strength, ANB-3066 propellant, SD-851-2 liner, and V-45 insulation from selected locations of three Minuteman Stage III motors. These data are to be used to relate the conditions of the dissected motors to those of operational motors (via excise samples) and to compare and adjust the age of all of these to the Stage II nominal liner degradation curve.

2.2 Testing/Monitoring of Motor TC 30024

The monitoring of motor TC 30024 and testing of accompanying motor segments are intended to determine if continued storage of motor TC 30024 will result in the worsening or healing of the liner condition and existing bondline separations in the motor.

2.3 Material Properties Testing of Dissected Motor TC 30072

The dissection of a Stage III motor from the operational force and testing of its material properties are intended to allow verification of motor aging predictions related to liner degradation by a determination of the longitudinal and circumferential bond strength profiles. Measurement of the bore surface propellant properties is used to verify satisfactory strain capability.

3.0 SUMMARY AND CONCLUSIONS

3.1 Twelve-Year Bondling Aging Study

Testing for the seven-year interval was performed on the forward flap and forward equator motor segments. As in the earlier test intervals, the results and trends were confirmed. The propellant/liner/insulation bond strength continues to decline with motor age. The rate of decline in the forward flap area has slowed with the mini DPT bond strength being about 34 psi. The decline in the forward equator was much greater than previous values, being down to approximately 51 psi from last year's value of 64 psi. A continuing increase in liner swell ratios and decline in liner gel fraction are further evidence of continued liner degradation. An additional decline in the relaxation modulus of propellant, particularly immediately adjacent to the liner interface, is again noted. Increases in the separation from termination in the bore to the aft flap hinge were observed. Separations at the 300 to 330 degree locations showed no appreciable changes, while inspection of the 20 to 290 degree motor locations show increases of +6 to +10.1 inches from the 64-month data.

3.2 Testing/Monitoring of Motor TC 30024

The visual and radiographic inspections of motor TC 30024 reveal moderate changes in the condition of the propellant/liner/insulation bondline during approximately two years of storage and monitoring at silo conditions.

3.3 Material Properties Testing of Dissected Motor TC 30072

Material properties of motor TC 30072 show the same trends as the three surveillance dissect motors. Liner degradation is evidenced by a decrease in mini DPT bond strength, increase in liner swell ratio, and decrease in

liner gel fraction. The bond strength (see Tables 32 to 37) follows the usual trends of being highest near the equator, lowest in the flap areas, and much better under and between the grounding straps.

Stress relaxation data for the propellant near the liner interface show a correlation between liner bond strength and relaxation modulus. The higher the bond strength, the higher the relaxation modulus.

Material properties of V-45 insulation from various motor locations were determined. The relaxation modulus is higher in the equator areas and lower near the flaps. V-45 swell ratios appear to be similar at all motor locations tested. V-45 moisture analysis showed a greater increase in percent moisture in the aft flap and forward equator regions with moisture content being lowest in the barrel area, between and under the grounding straps.

4.0 METHOD

4.1 Material Properties Testing

Insofar as possible, all testing of motor segment or excise sample material properties throughout the bondline study has been carried out in a uniform fashion and according to the following test methods.

4.1.1 Segment Sampling

The foil/epoxy seal and any interfering fiberglass case material is removed from the motor segments prior to test sample preparation using these procedures:

DP 2413-018, Cutting of Stage III Minuteman Segments for Lab Sample Preparation

DP 2413-021, Minuteman Stage III Fiberglass Case Removal From Motor Segments by Grit Blasting

4.1.2 Mechanical Property Test Methods

4.1.2.1 Mini DPT Bond Tensile

DP 2413-008, Preparation of Mini Double Plated Tensile (Mini DPT) Bond Strength Specimens

DP 2413-013, Testing of Mini Double Plated Tensile (Mini DPT) Bond Strength Specimens

4.1.2.2 Propellant Relaxation Modulus

DAP 0270, Determination of Relaxation Modulus of Propellant by Use of Mini Tensile Specimens

DP 2413-015, Stress Relaxation Testing Using the Instron Tensile Tester

4.1.2.3 Shore A Hardness (15-Second)

SOP 325, Section 6

4.1.2.4 Propellant Mini Tensile

SLP-528, Mechanical Forming of Propellant Specimens

DP-2413, Operation of Instron Tensile Testing Instruments

4.1.2.5 V-45 Relaxation Modulus

LTP-2413-0151, Preparation of Rubber Stress Relaxation Specimens from Motor Segments

DP 2413-015, Stress Relaxation Testing Using the Instron Tensile Tester

4.1.2.6 SD-851-2 Liner Relaxation Modulus

SLP-472, Penetrometer Hardness Testing of Liner Propellant Bond

4.1.3 Chemical Property Test Methods

4.1.3.1 SD-851-2 Liner Moisture

DAP 0269, Determination of Moisture in SD-851-2 Liner

4.1.3.2 SD-851-2 Liner Solvent Swell Ratio

DAP 0197, Determination of Solvent Swell Ratio of Cured Liner from MM III Stage Samples

4.1.3.3 SD-851-2 Liner Gel Fraction

DAP 0254, Determination of Minuteman III Stage Liner Gel Fraction

4.1.3.4 V-45 Moisture Content

4.1.3.4.1 Azeotropic Distillation

DAP 0321, Determination of Moisture in Rubber by Azeotropic Distillation

4.1.3.4.2 DuPont Moisture Analysis

DAP 0317, Determination of Moisture in V-45 and C-4 Insulation by DuPont Moisture Evolution Analyzer

4.1.3.5 V-45 Swell Ratio

DAP 0197, Determination of Solvent Swell Ratio of Cured Liner from MM III Stage Samples

4.1.3.6 V-45 DOP Content

DAP 0300, Determination of DOP in V-45 Rubber

4.1.3.7 SD-851-2 Liner C=O/C=C Absorbance Ratio

DAP 0399, Infrared Analysis Using the Nicolet 7199 FTIR

4.1.4 Evaluation of Material Properties Test Results

Once the testing of the motor segments was accomplished, results were compared with those from earlier test intervals or other aging and surveillance motors. This was done largely through the use of plots of measured values versus conditioning time or motor location.

4.2 Twelve-Year Bondline Aging Study

As at earlier test intervals, the designated segments (see Figure 2 and Table 1) were removed singly from conditioning, the foil/epoxy seal was removed, and lab specimens were prepared and tested in accordance with Table 2 and the above cited methods. While awaiting testing, the specimens were kept tightly sealed in aluminum foil to minimize loss of moisture.

4.3 Testing/Monitoring of Motor TC 30024

Simulated silo conditioning of motor TC 30024 at $70^{o} \pm 5^{o}$F and 50 $\pm$ 5 percent RH was continuous except for brief periods to allow for visual inspection approximately monthly and radiographic inspections on a six-month basis. These inspections, performed in accordance with the test matrix shown in Table 23, were compared with each other and with earlier (LRSLA) inspections, provide the basis for determining actual changes with time in the bondline and grain configuration of motor TC 30024.

Additional information as to the present condition of the bondline and propellant in motor TC 30024 is being obtained by periodic testing of the material properties of segments from motor TC 30050 (see test matrix in Table 24). These segments accompanied motor TC 30024 throughout the LRSLA SAT conditioning, and in that accelerated aging test, motor TC 30050

segments were laboratory tested to verify that the liner in the forward flap region of the intact motors, TC 30024 and TC 30106, was fully degraded. The first testing of these segments under the surveillance program was performed in September 1981, after additional storage with motor TC 30024 at silo conditions for about 1.5 years. All tests at the present and at earlier times were performed in accordance with the test procedures cited in Section 4.1.

4.4 Material Properties Testing of Dissected Motor TC 30072

The full dissection and material properties testing of Stage III motors from the operational force was first proposed in 1981[1], but the first such motor, TC 30072, did not become available until early 1983. With its availability came a request that the test plan be revised to provide for additional material properties testing to track the bondline condition to at least 17 years of motor age. Without making changes in the original dissection plan or deleting any of the originally planned material properties testing, the test plan was revised[2]. The current plan makes use of motor segments that would have otherwise gone unused and provides for annual testing to 1989 (Table 28), or about 17.5 years of age for motor TC 30072.

Following dissection of motor TC 30072 by Operations personnel, further subsectioning of the motor segments and preparation and testing of laboratory specimens was performed by workers in the Research and Development Laboratories. This testing was performed in accordance with the methods cited above, and results are presented in Section 5.2.

[1]TWR-20946, "Test Plan, Minuteman Stage III, Operational Surveillance Program, Addenum No. 1," January 1981.

[2]TWR-20946, "Test Plan, Minuteman Operational Surveillance Program, Addendum No. 2," May 1983.

5.0 RESULTS

5.1 Twelve-Year Bondline Aging Study

The plan for motor segment use and the material properties test matrix for the 12-year (1978 to 1990) bondline aging study using motors TC 30005, TC 30019, and TC 30033 are shown in Tables 1 and 2. The motor segment layout is in Figure 2. The results of the material properties testing at the seven-year test interval (actually 76 months of conditioning at 70°F and 50 percent RH) are summarized in Figures 3 to 24 and Tables 3 to 22. In the latest testing, only the forward flap and forward equator segments were tested, as planned. Earlier trends and results tend to be confirmed. As noted in previous test intervals, the motor-to-motor differences in general are small.

The propellant/liner/insulation bond tensile strength continues to drop off with increasing motor age or conditioning time. At the 76-month interval, the bond strength (34 psi) is approximately the same as the 64-month data in the forward flap area (see Figure 3). In the forward equator, bond strength has dropped from 64 psi at 64 months to 51 psi at 76 months. In the forward flap area, the liner swell ratio has increased to a value of 2.13, and the liner gel fraction has decreased to a value of 0.40. These results confirm that degradation continues to be least in the most protected locations, that is where moisture enters with difficulty, as at the forward equator and two inches aft of the forward equator.

Propellant relaxation modulus has declined with storage time, particularly immediately adjacent to the liner interface. This effect can be caused by moisture effects and migration of DOP plasticizer from the V-45 insulation: the amount of contribution of each to the degradation has not been identified.

5.2 Testing/Monitoring of Motor TC 30024

5.2.1 Motor Inspection

Radiographic inspections of motor TC 30024 revealed evidence of further liner degradation in some areas while other areas showed no appreciable change. More degradation was evident in the flap bulb area. The separations that were found between the aft polar boss insulation and glass at the aft tip have not changed. There was also no evidence of change in the forward flap area. However, new separations from the in bore to 12 inches aft of the aft flap bulb hinge were detected in Area A at 172 deg angular location.

Visual inspections of motor TC 30024 have shown no trends in the physical measurements to indicate significant changes in either the motor bore diameter or the forward gap area. There is also no apparent hardening of the propellant surface in the aft bore. The latest Shore A readings ranged from 74-79, slightly lower than values for August 1981.

5.2.2 Segment Testing

The results of material properties testing of the motor TC 30050 segments that have accompanied motor TC 30024 since the LRSLA Simulated Aging Test conditioning are summarized in Figures 26 to 32 and Tables 25 to 27. The bond strength and liner gel fraction show a slight decrease in values as compared to baseline data. Liner swell ratios also follow a similar trend with a slight increase in swell ratio values.

5.3 Material Properties Testing of Dissected Motor TC 30072

The plans for baseline and later testing of the material properties of dissected operational motor TC 30072 are shown in Tables 28 to 31. The designation of specific motor segments is obtained from Figures 34 to 39. The results of the 1985 material properties testing are summarized in Figures 40 to 62 and Tables 32 to 48.

5.3.1 Bond Strength and Liner Properties

The motor TC 30072 propellant/liner/insulation bond strength and liner properties test results are summarized in Figures 40 to 48 and Tables 32 to 37.

The effects of motor location and crosshead test rate on mini DPT bond strength are seen in Figures 40 and 41. The bond strength is highest in the barrel region and near the equators where there is the lowest moisture penetration. Also evident is the existence of lower bond strength in the forward end of the motor than in the aft end. The motor profiles of liner gel fraction and liner swell ratio show a trend for a decrease in gel fraction and increase in swell ratio values. Liner swell ratio values show a decrease in the more protected barrel region.

5.3.2 Relaxation Modulus of Propellant at the Bondline

Stress relaxation testing results for motor TC 30072 are shown in Figures 49 to 61 and Tables 38 to 45. The previously noted trend of lower propellant stress relaxation modulus in the forward end of the motor and higher modulus in the barrel near the equators and under the grounding straps is still in evidence. This correlation suggests the relationship of bond strength to propellant relaxation modulus.

5.3.3 V-45 Insulation Material Properties

The relaxation modulus, moisture content, dioetylphthalate (DOP) plasticizer content, and swell ratio of V-45 insulation were determined in various locations of motor TC 30072. The V-45 relaxation modulus is typically lowest in the equator region and highest in the forward and aft flaps. The V-45 moisture content results show that the percent moisture is lowest in the barrel region. The test results are summarized in Tables 44 to 48.

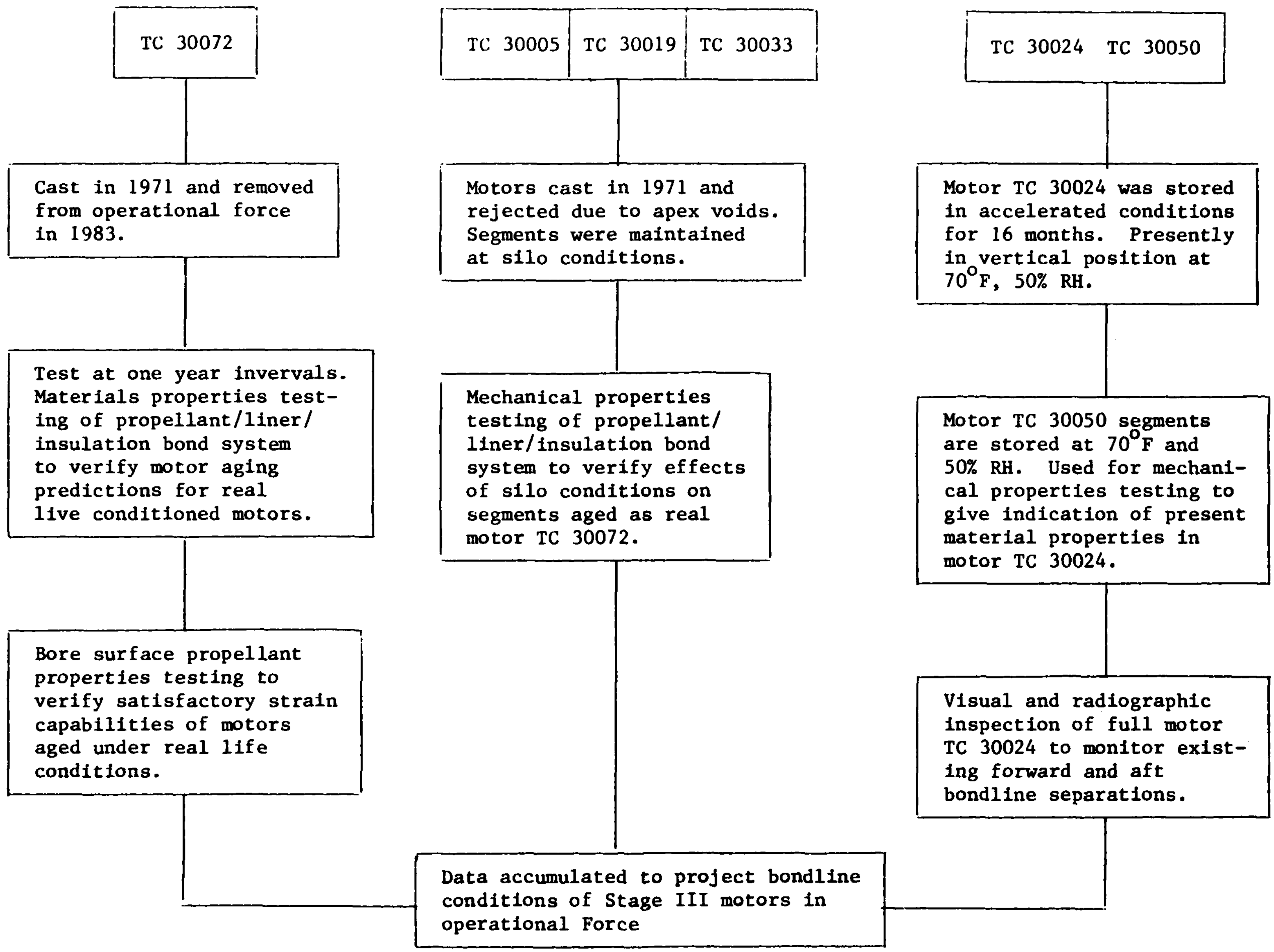


Figure 1. Definition Flowchart for Minuteman Stage III Surveillance Program

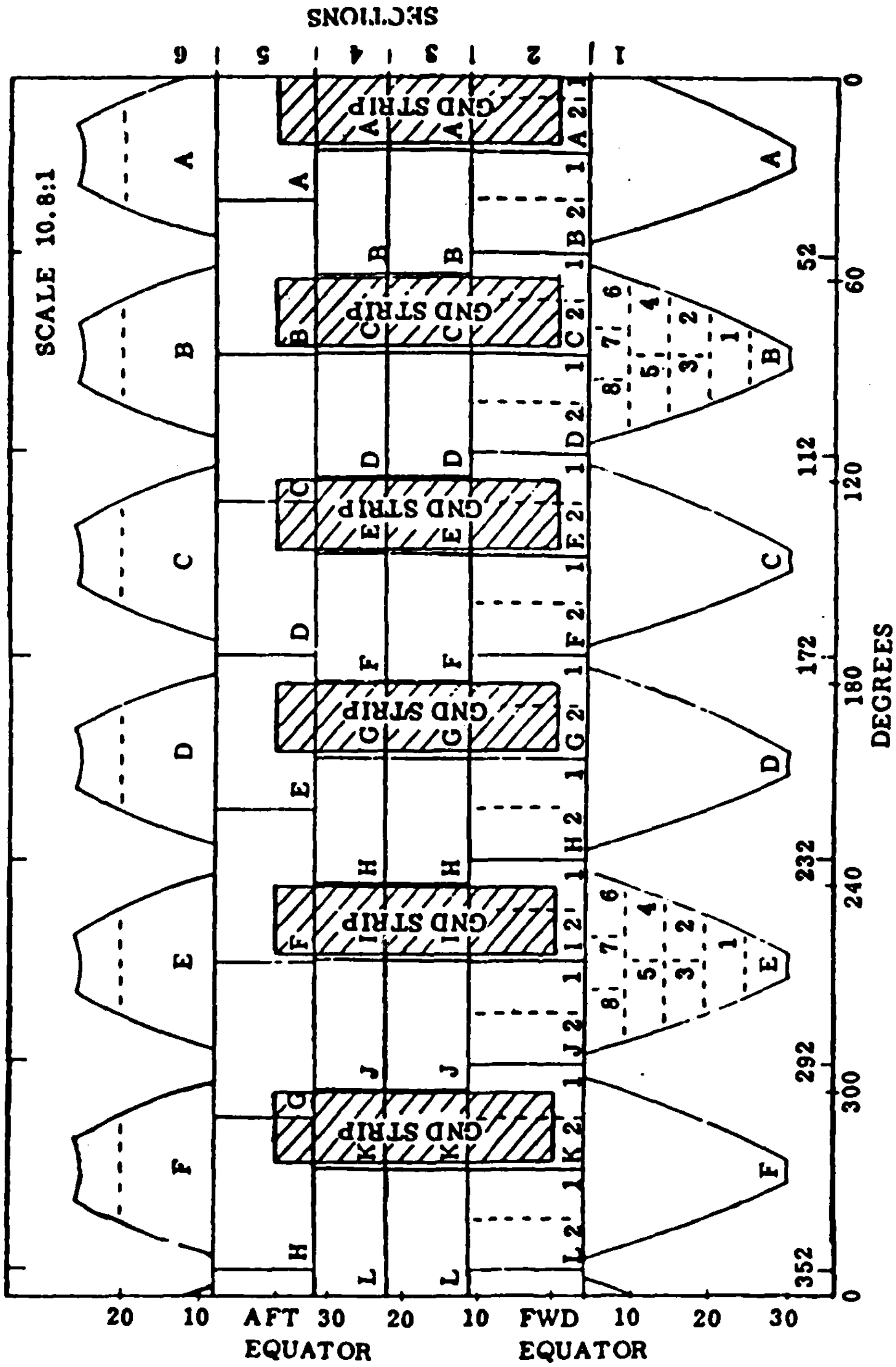


Figure 2. Motor Segment Layout

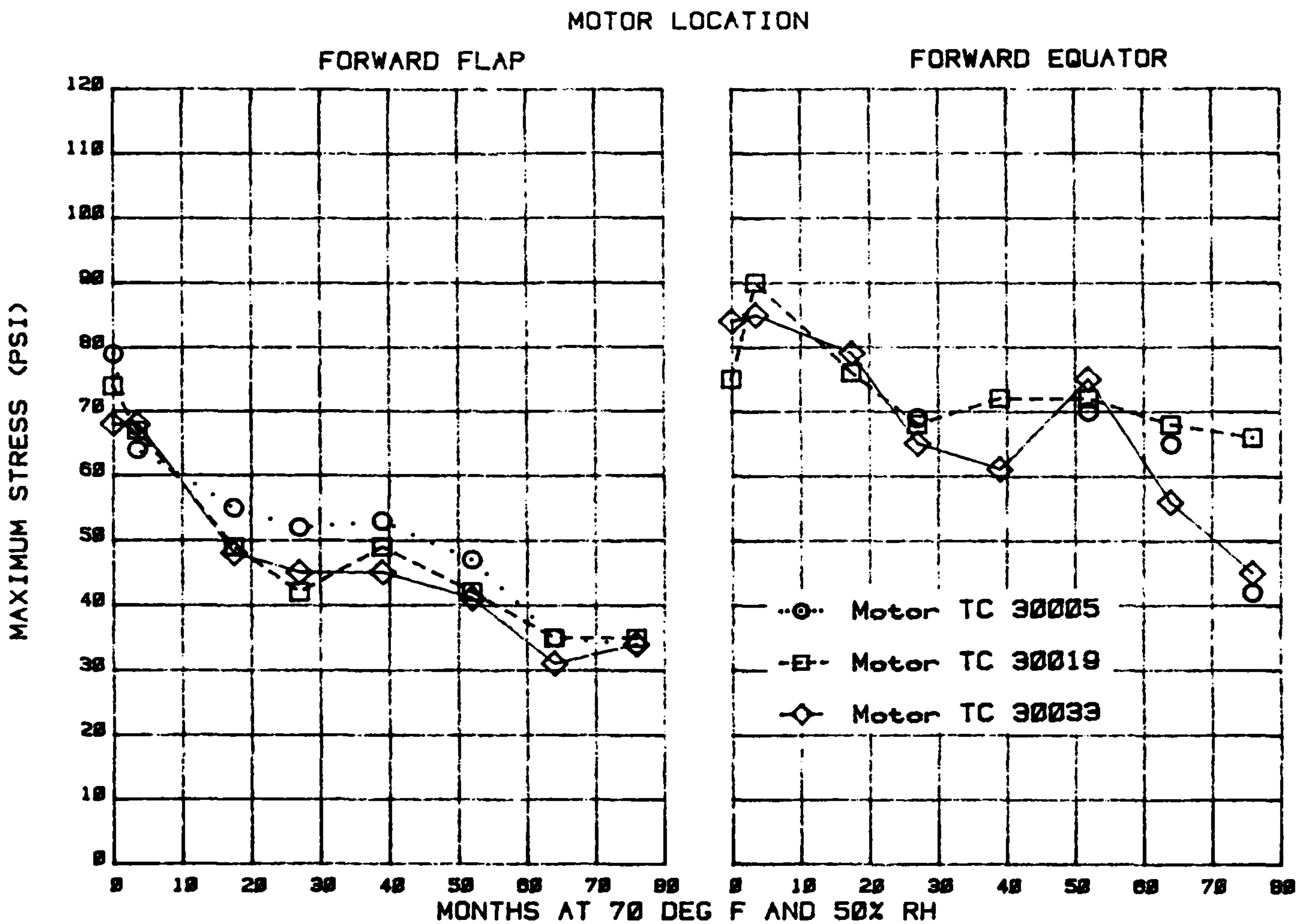


Figure 3. Effect of Storage Conditions Upon Mini DPT Bond Strength in the Forward Flap and at the Forward Equator

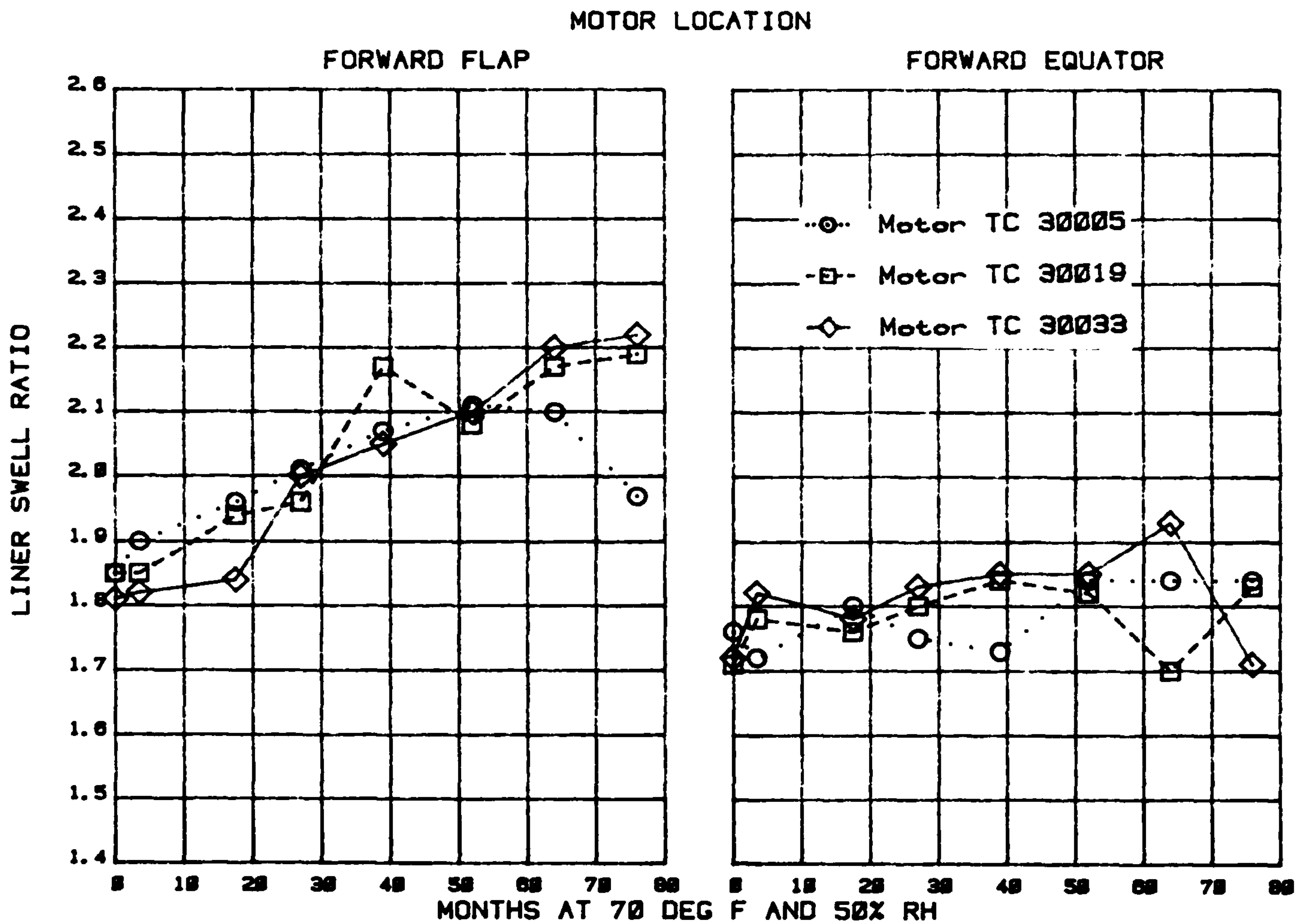


Figure 4. Effect of Storage Conditions Upon Liner Swell Ratio at the Forward Flap and Forward Equator

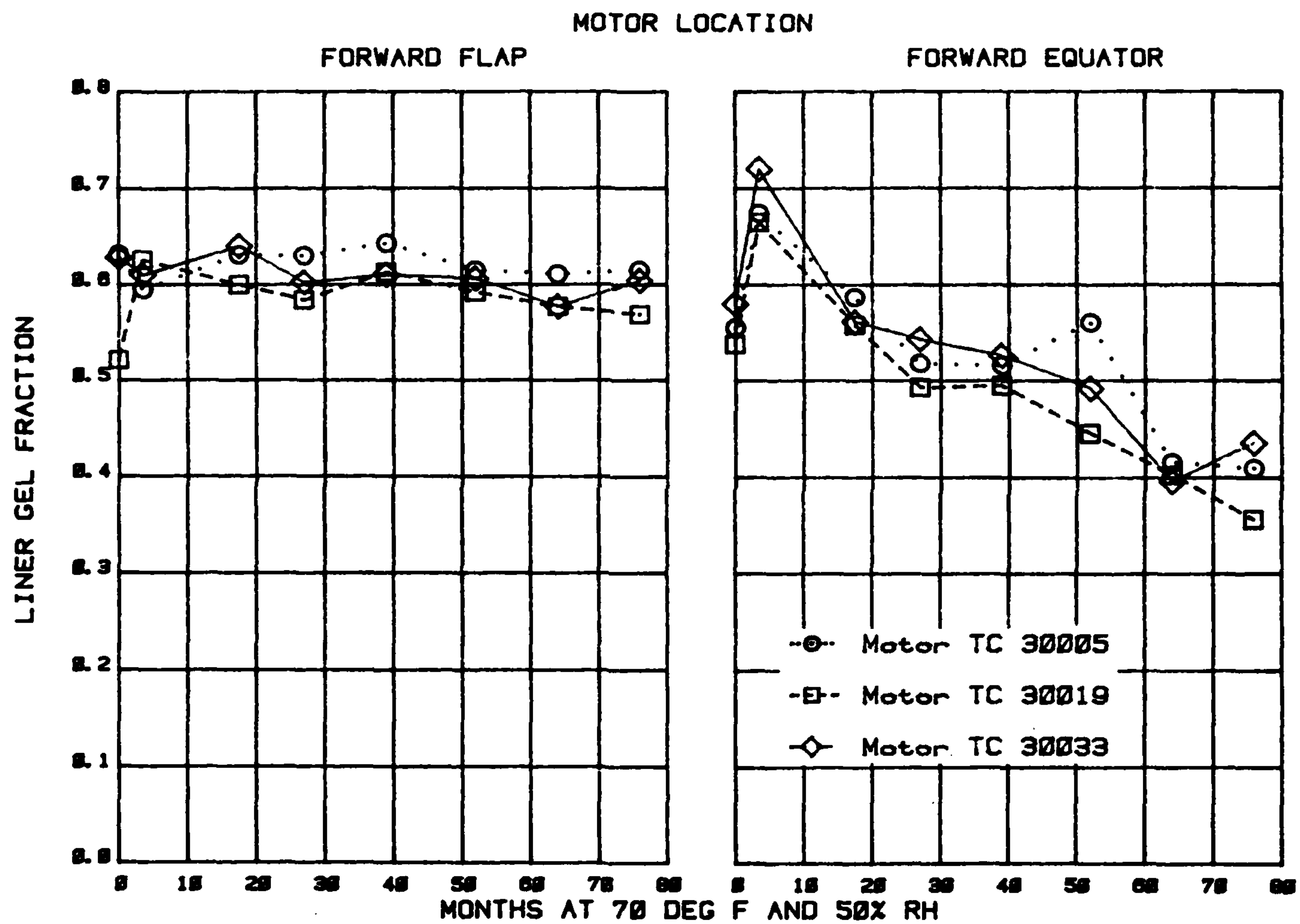


Figure 5. Effect of Storage Conditions Upon Liner Gel Fraction at the Forward Flap and at the Forward Equator

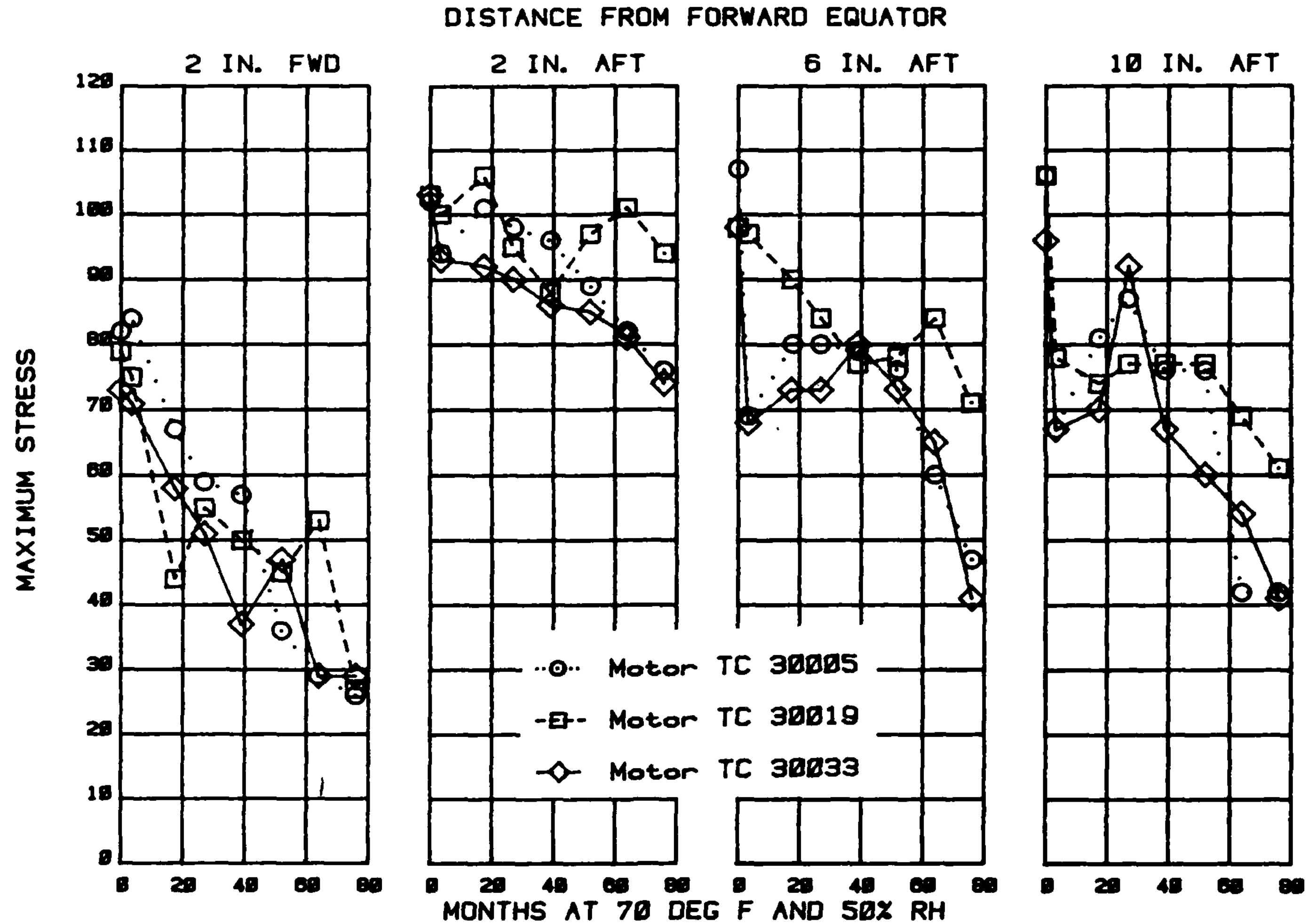


Figure 6. Effect of Storage Conditions Upon Mini DPT Bond Strength Near the Forward Equator

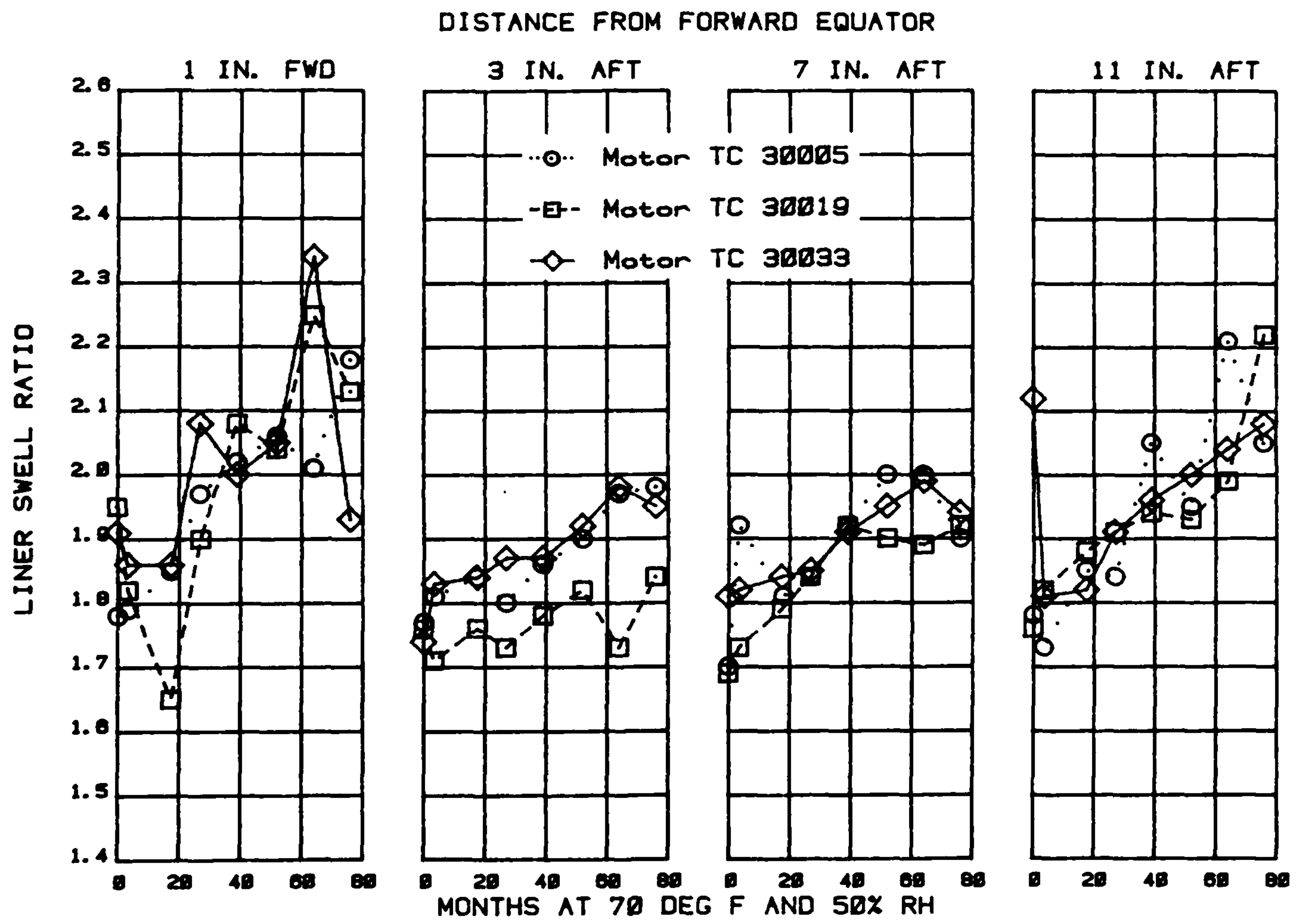


Figure 7. Effect of Storage Conditions Upon Liner Swell Ratio Near the Forward Equator

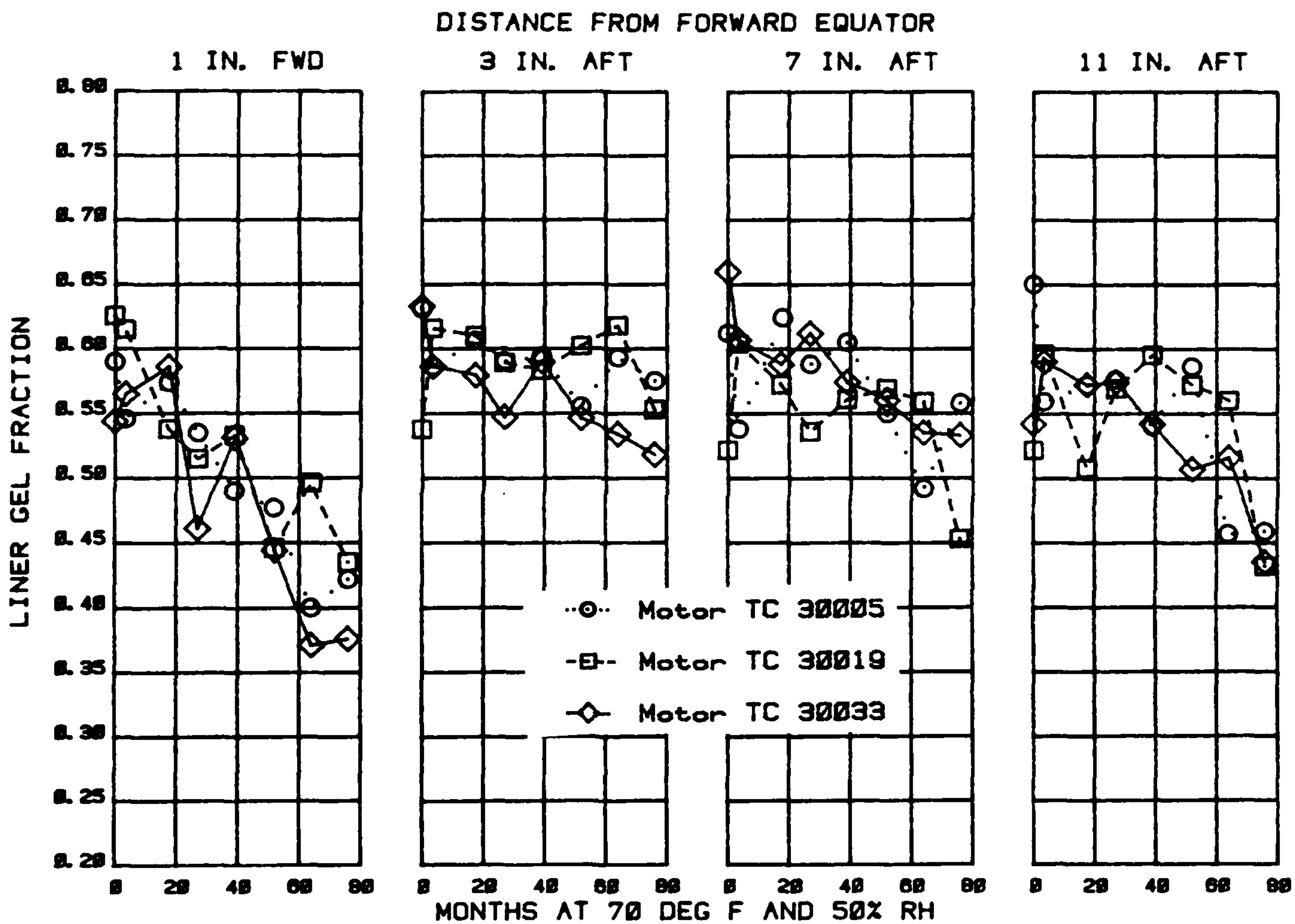


Figure 8. Effect of Storage Conditions Upon Liner Gel Fraction Near the Forward Equator

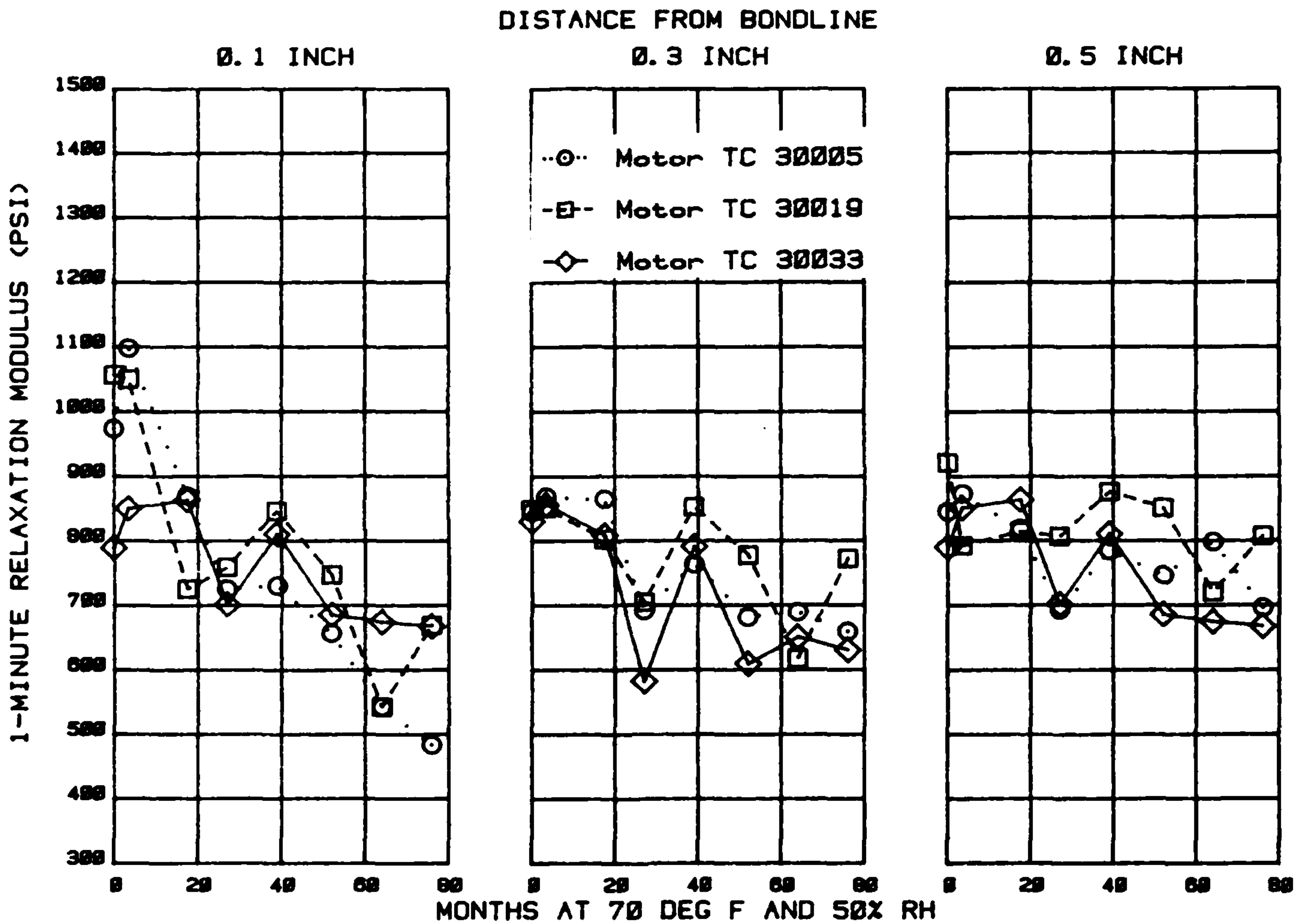


Figure 9. Effect of Storage Conditions Upon Propellant Relaxation Modulus in the Forward Flap Area

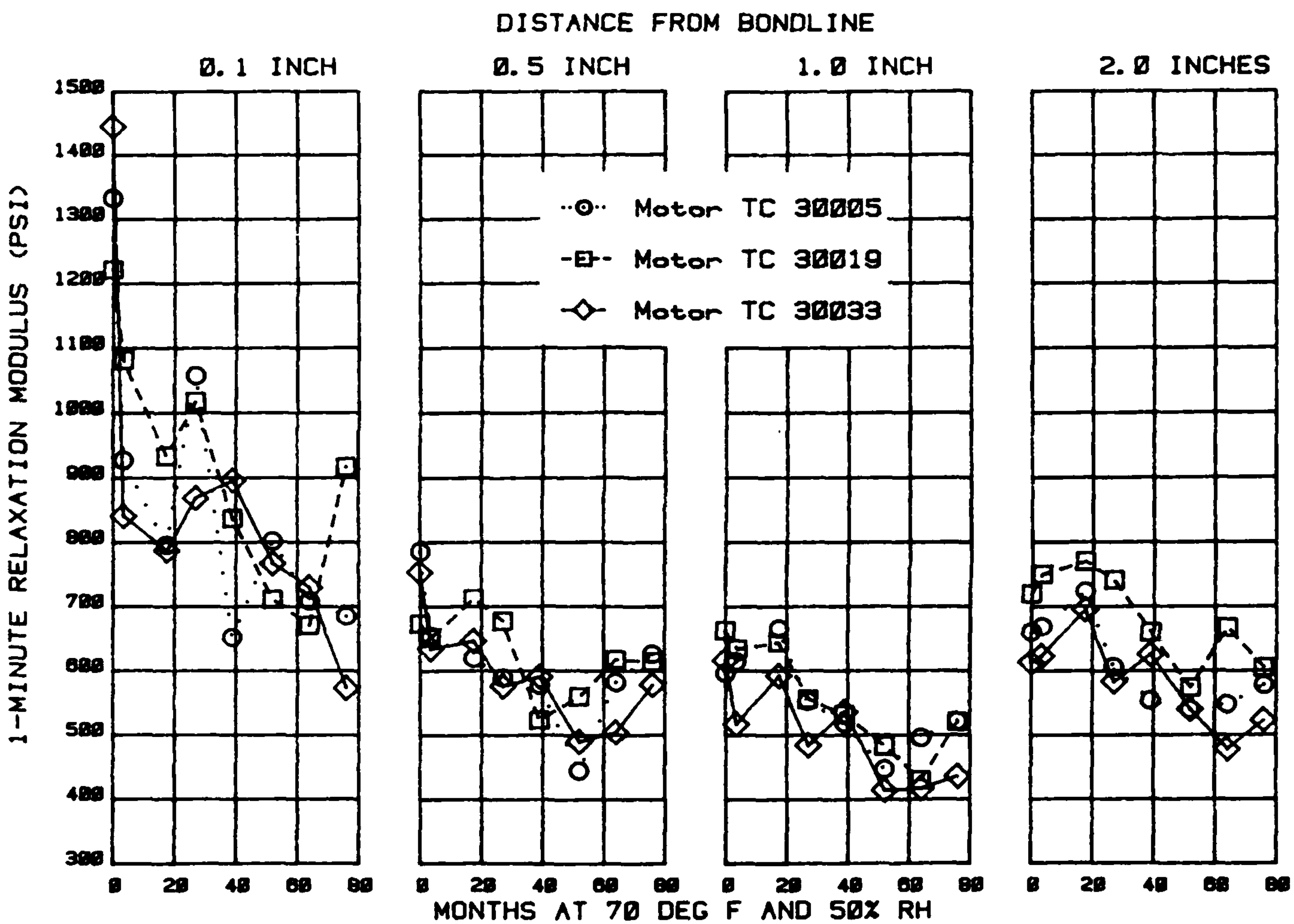


Figure 10. Effect of Storage Conditions Upon Propellant Relaxation Modulus at the Forward Equator

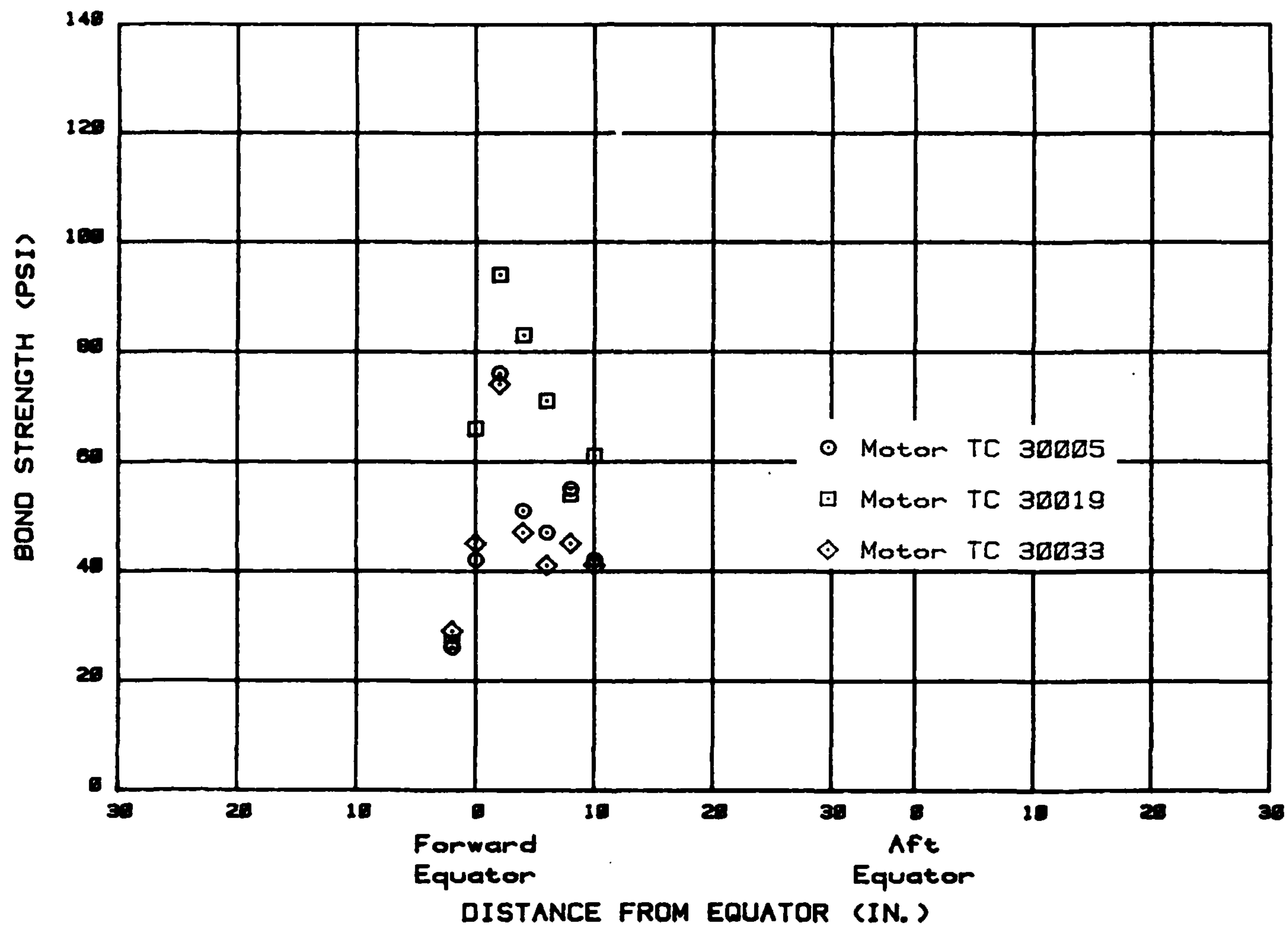


Figure 11. Mini DPT Bond Strength at Various Motor Locations

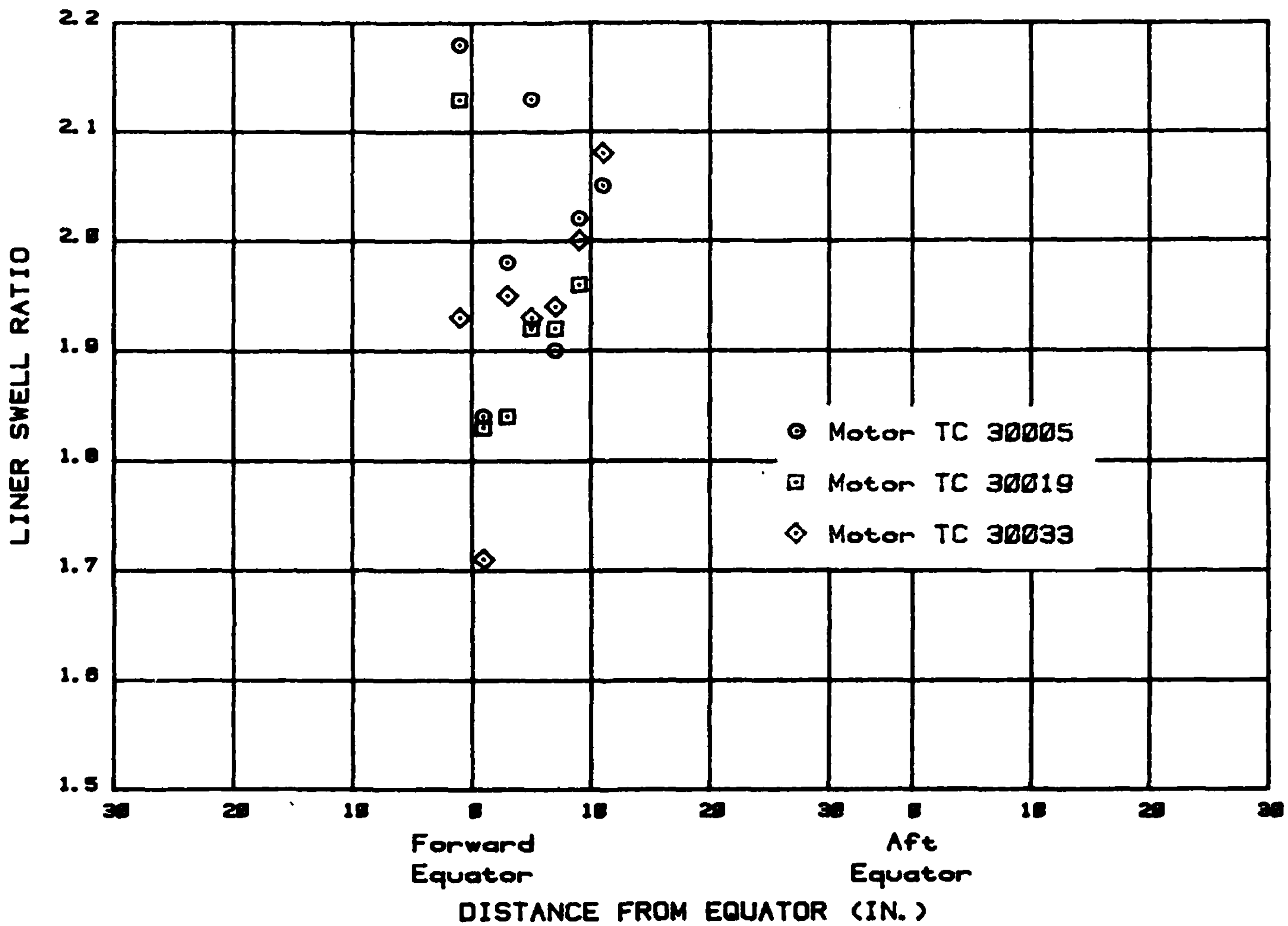


Figure 12. Liner Swell Ratio at Various Motor Locations

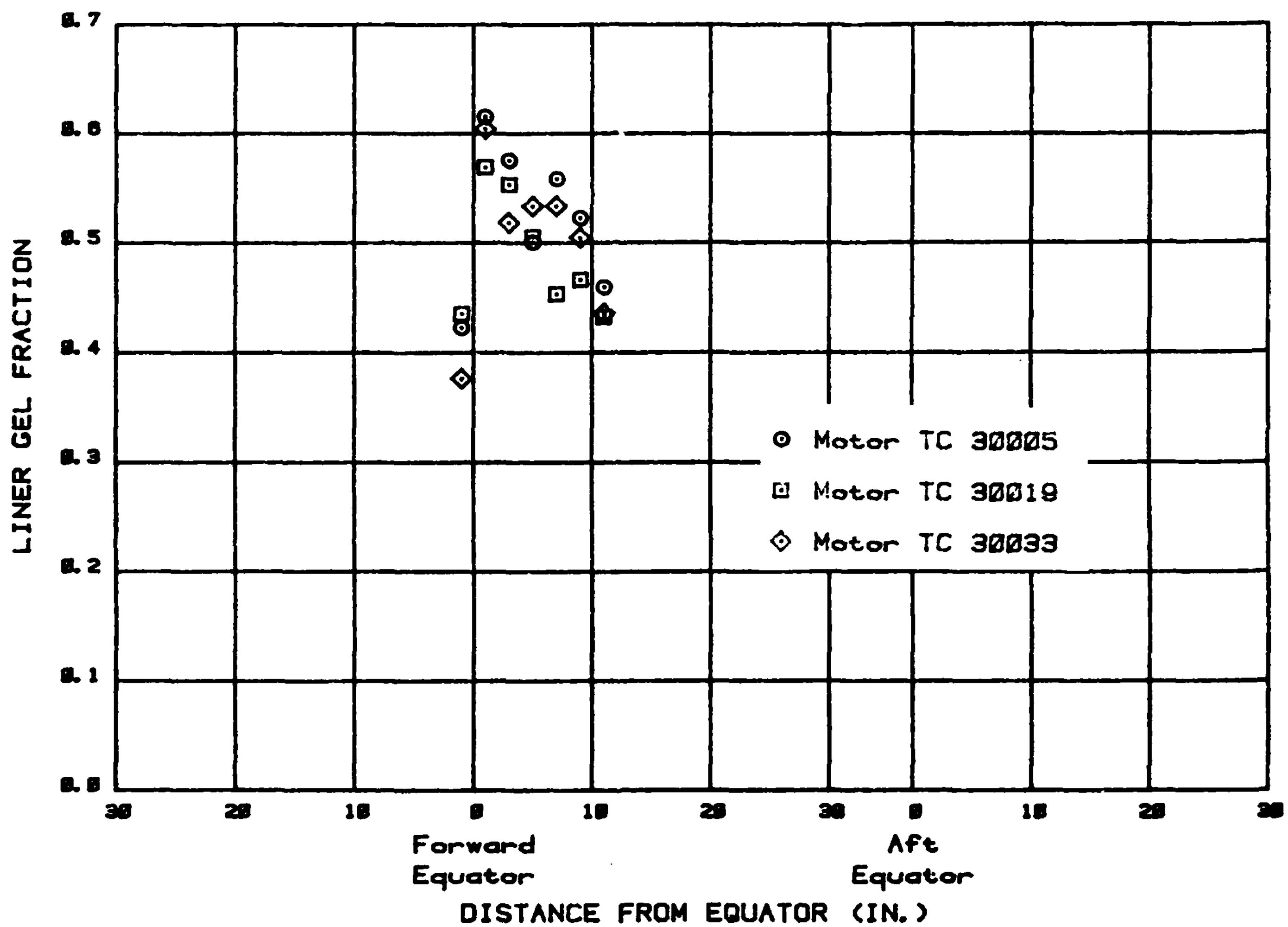


Figure 13. Liner Gel Fraction at Various Motor Locations

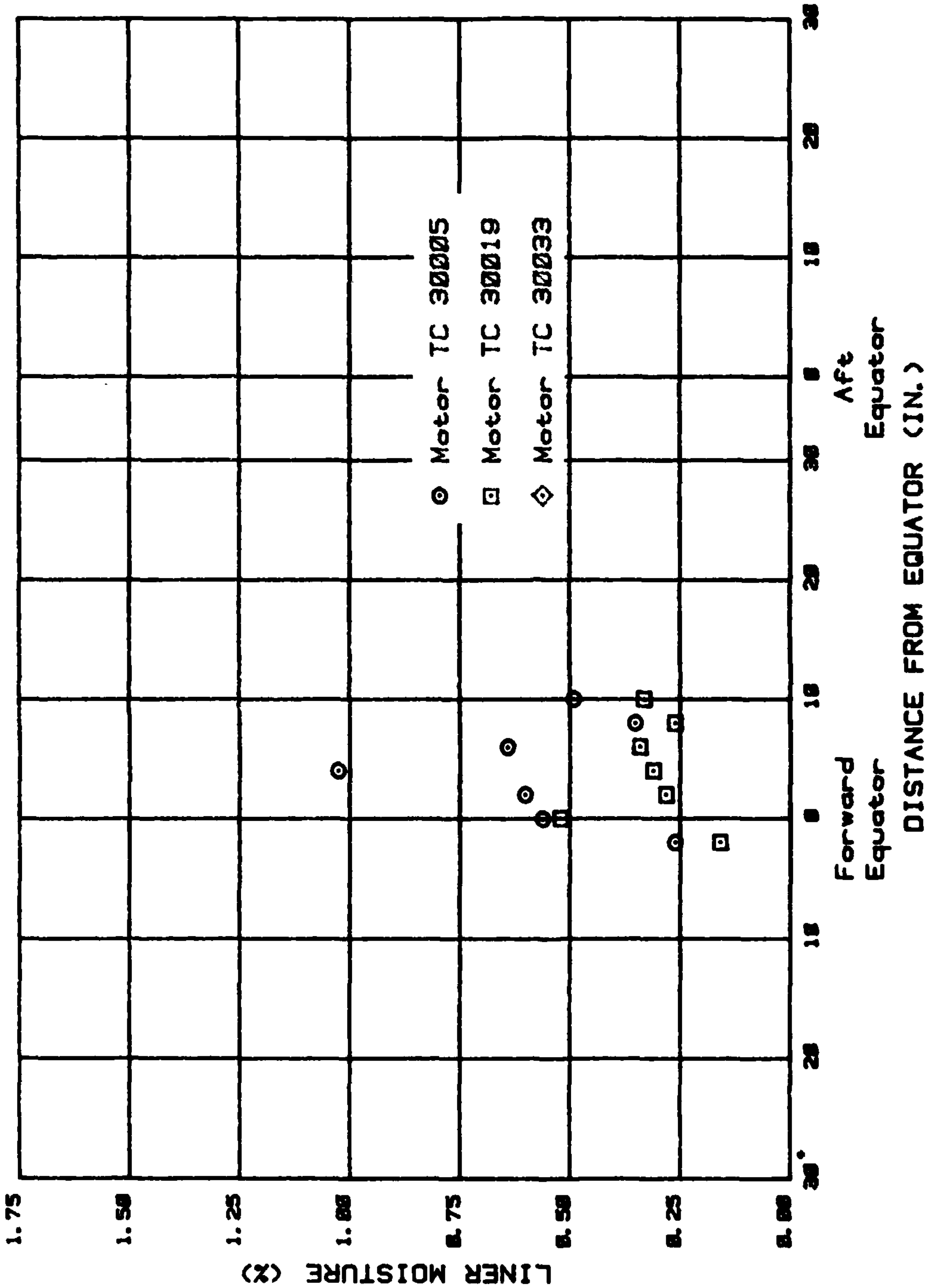


Figure 14. Liner Moisture at Various Motor Locations

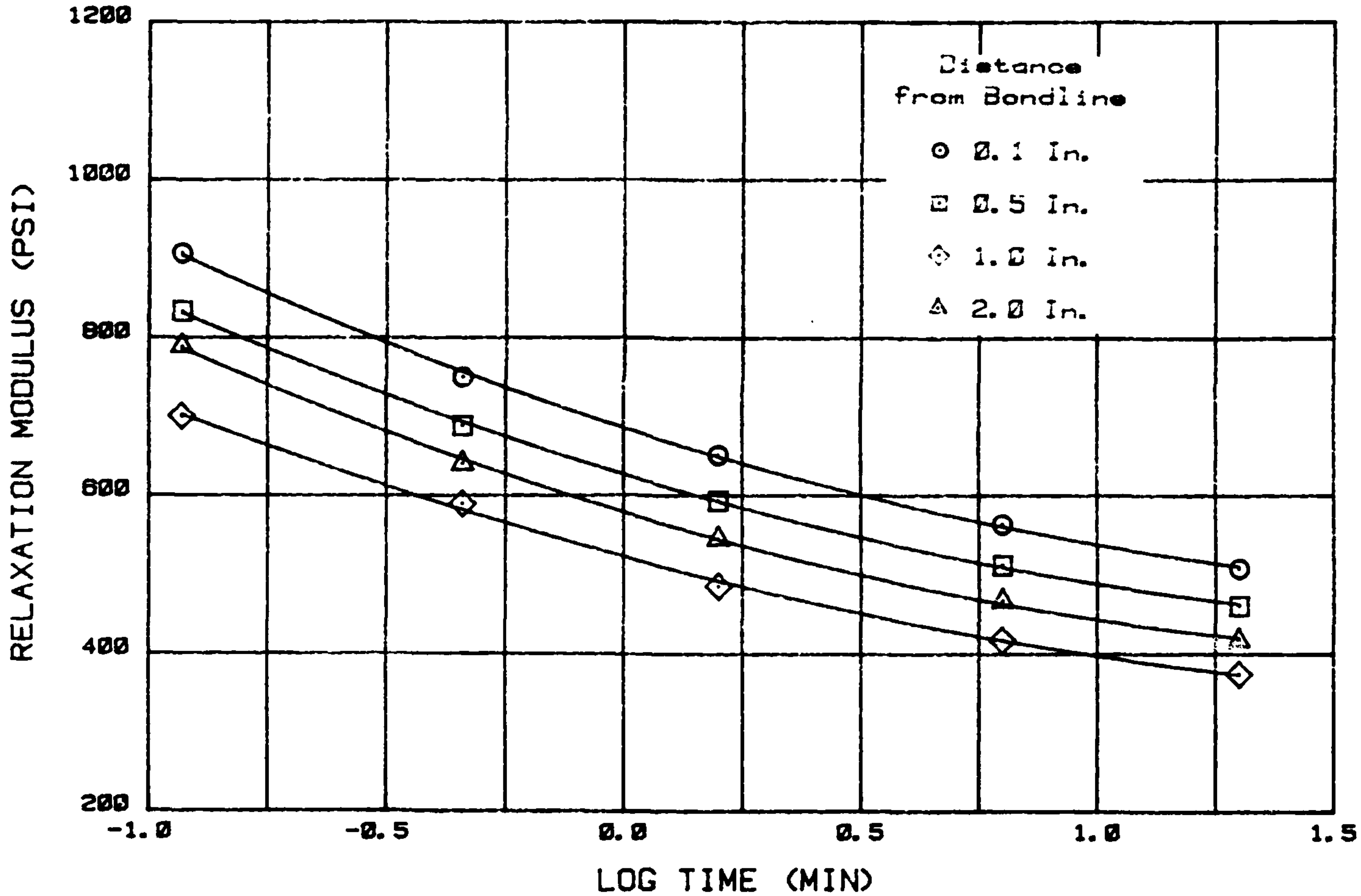


Figure 15. Motor TC 30005 Relaxation Modulus of ANB-3066 Propellant at the Forward Equator

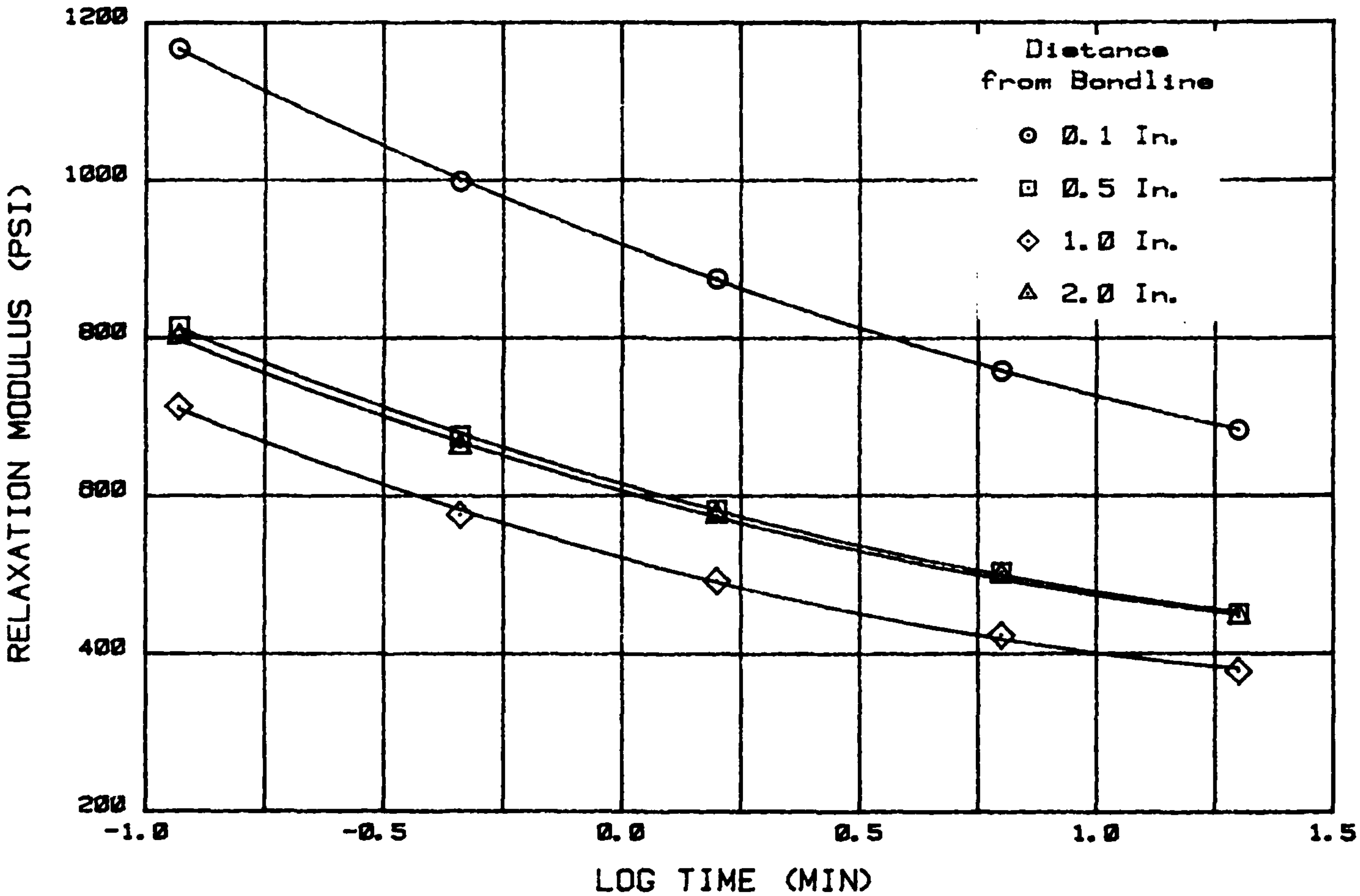


Figure 16. Motor TC 30019 Relaxation Modulus of ANB-3066 Propellant at the Forward Equator

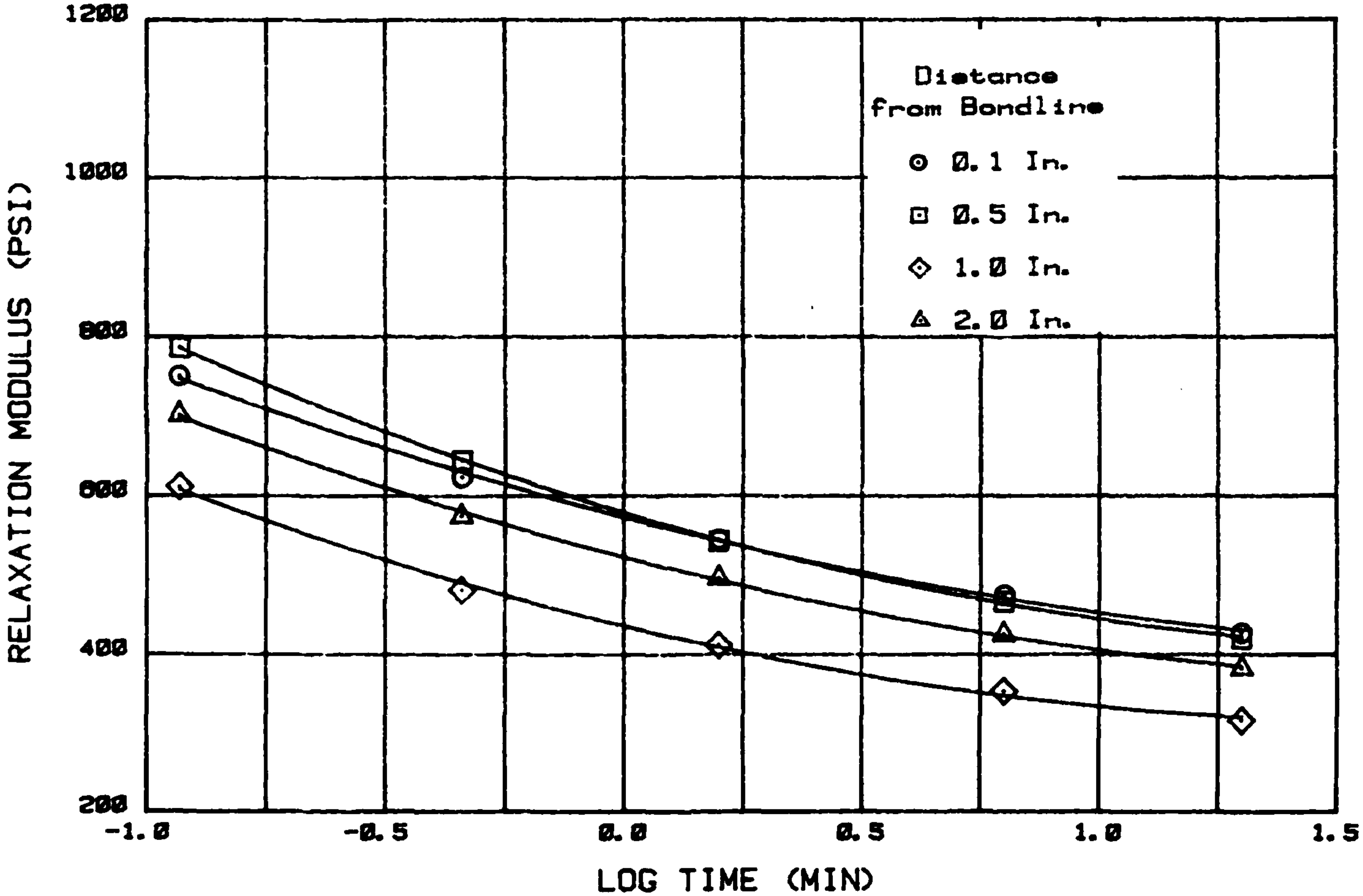


Figure 17. Motor TC 30033 Relaxation Modulus of ANB-3066 Propellant at the Forward Equator

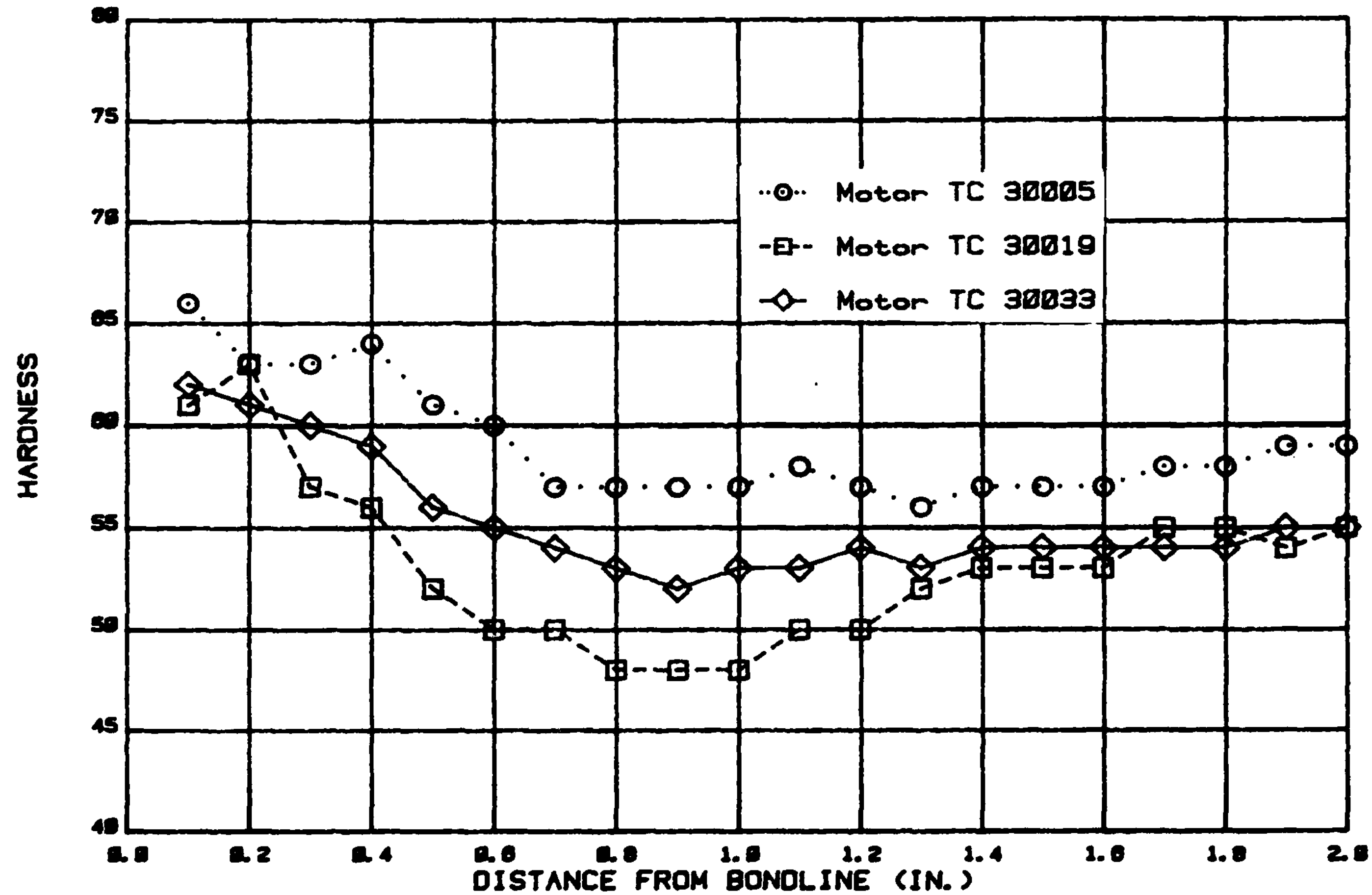


Figure 18. Shore A Hardness Gradient of ANB-3066 Propellant at the Forward Equator

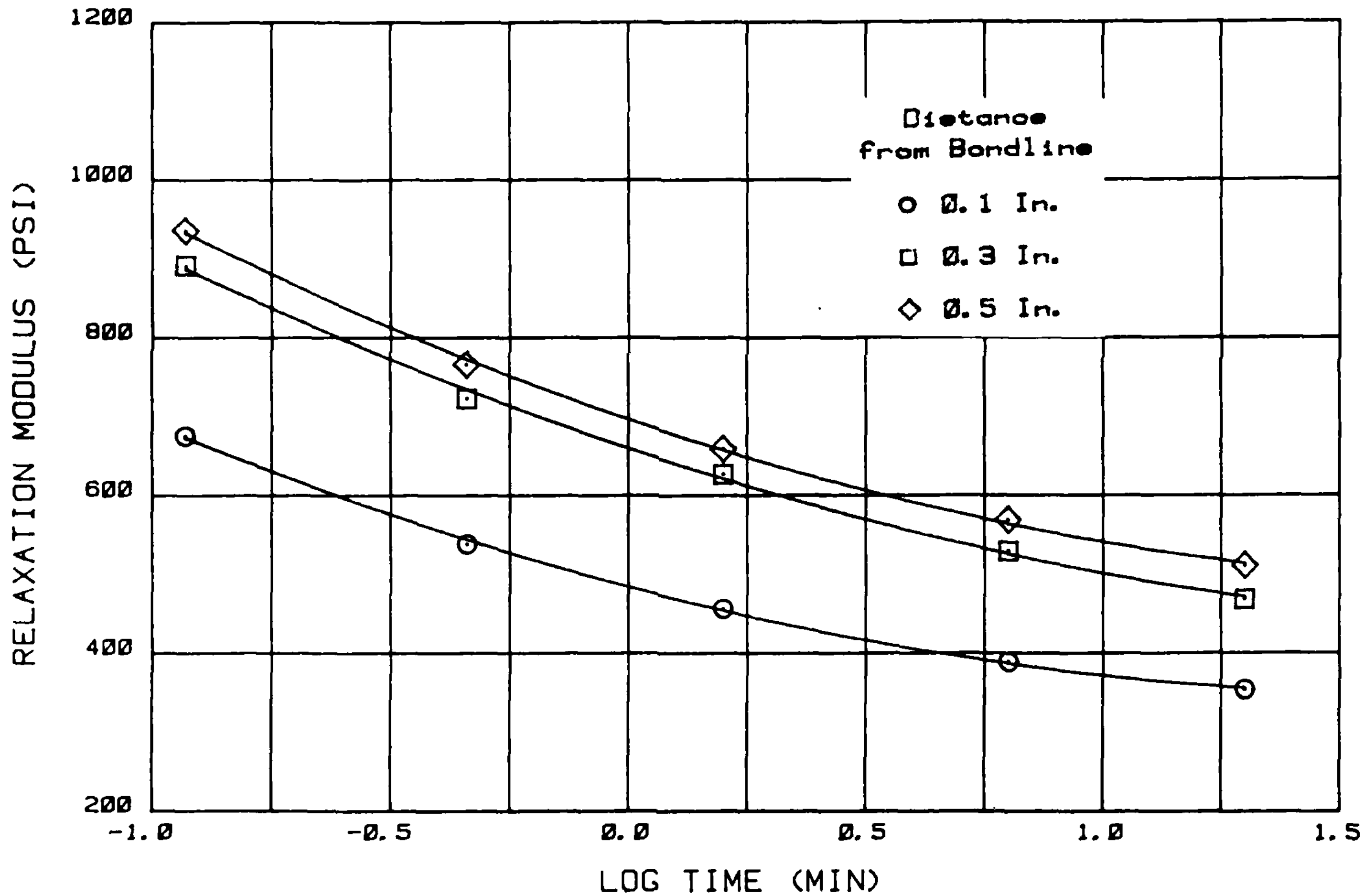


Figure 19. Motor TC 30005 Relaxation Modulus of ANB-3066 Propellant in the Forward Flap Area

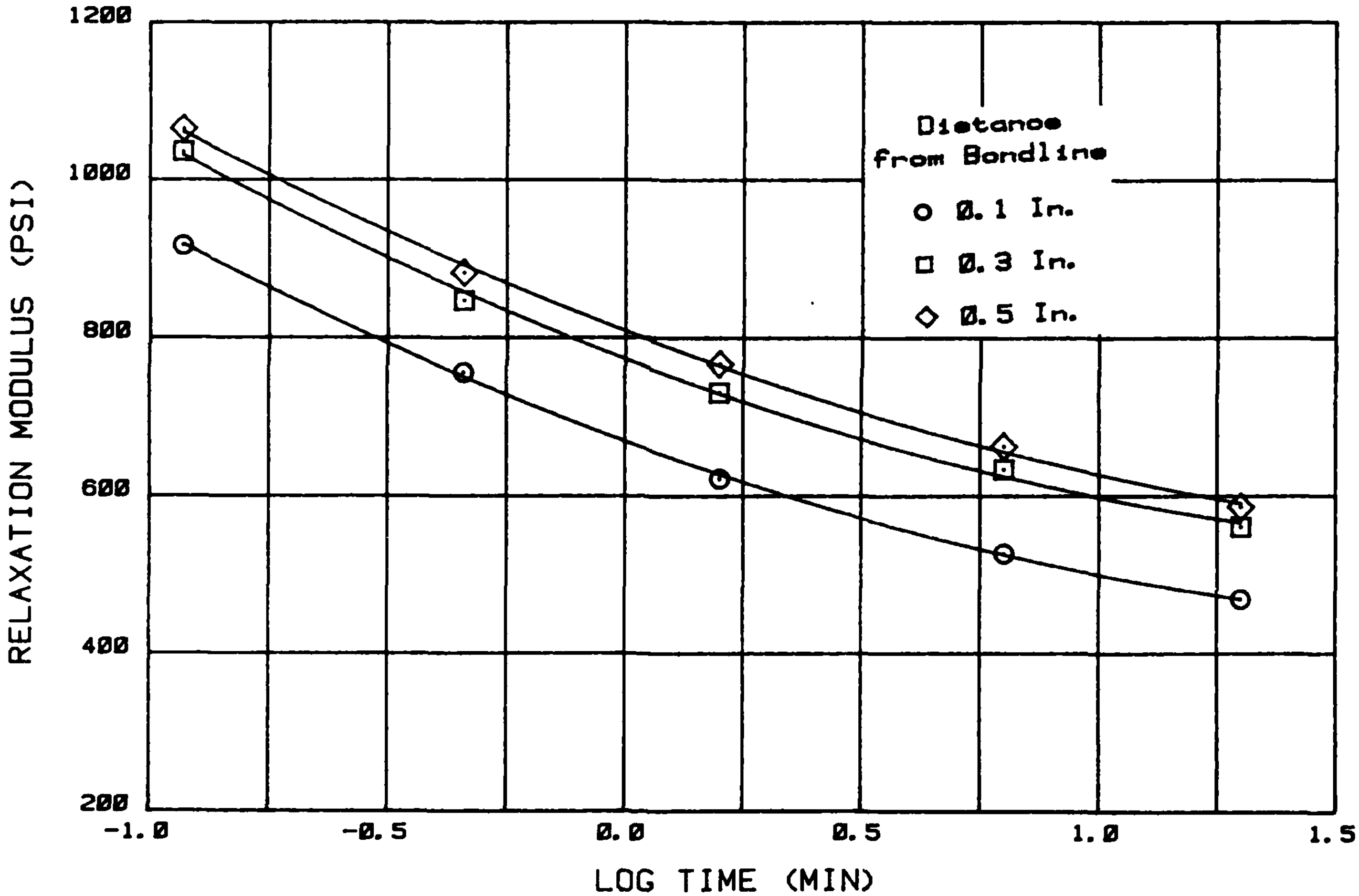


Figure 20. Motor TC 30019 Relaxation Modulus of ANB-3066 Propellant in the Forward Flap Area

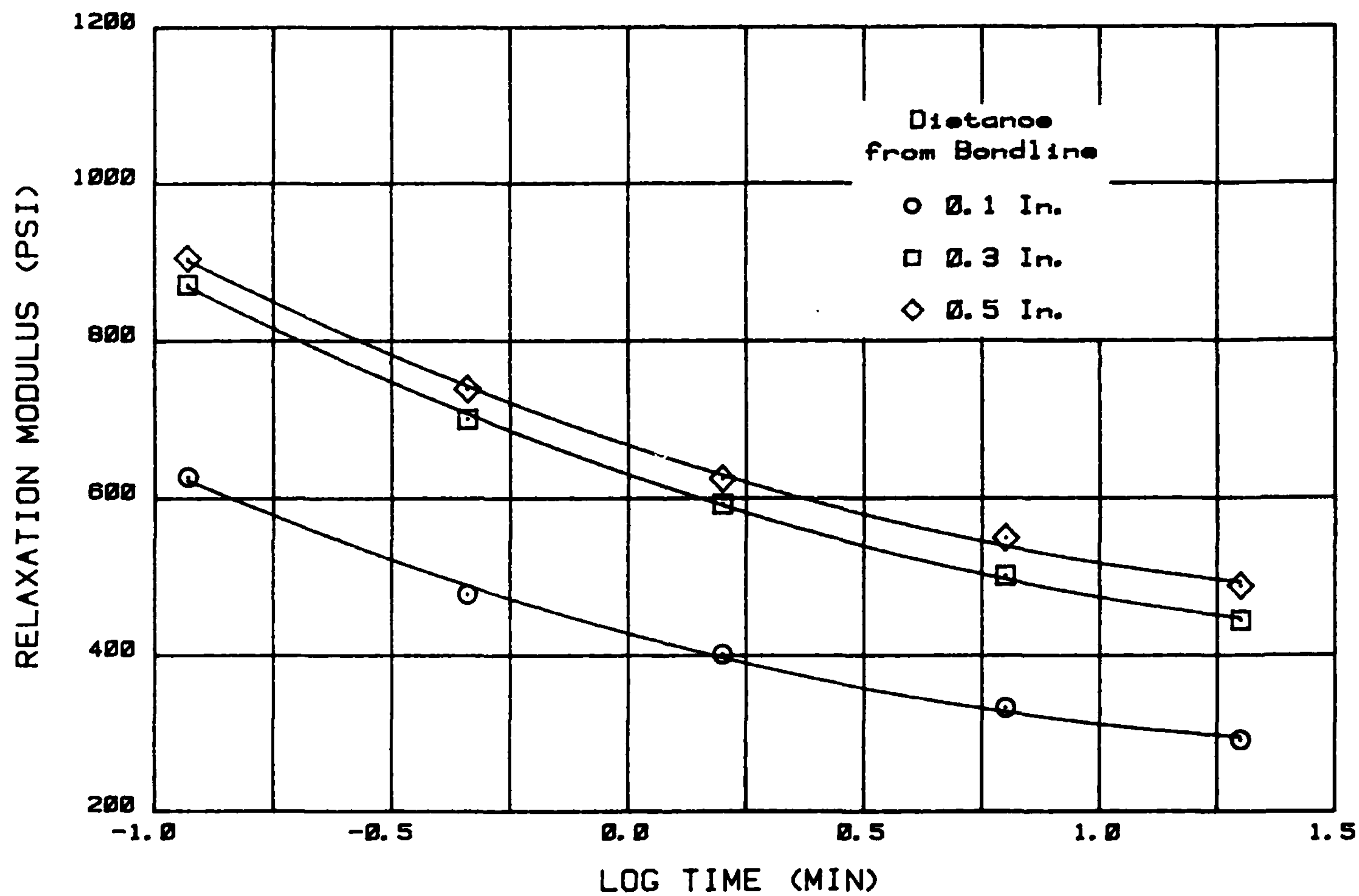


Figure 21. Motor TC 30033 Relaxation Modulus of ANB-3066 Propellant in the Forward Flap Area

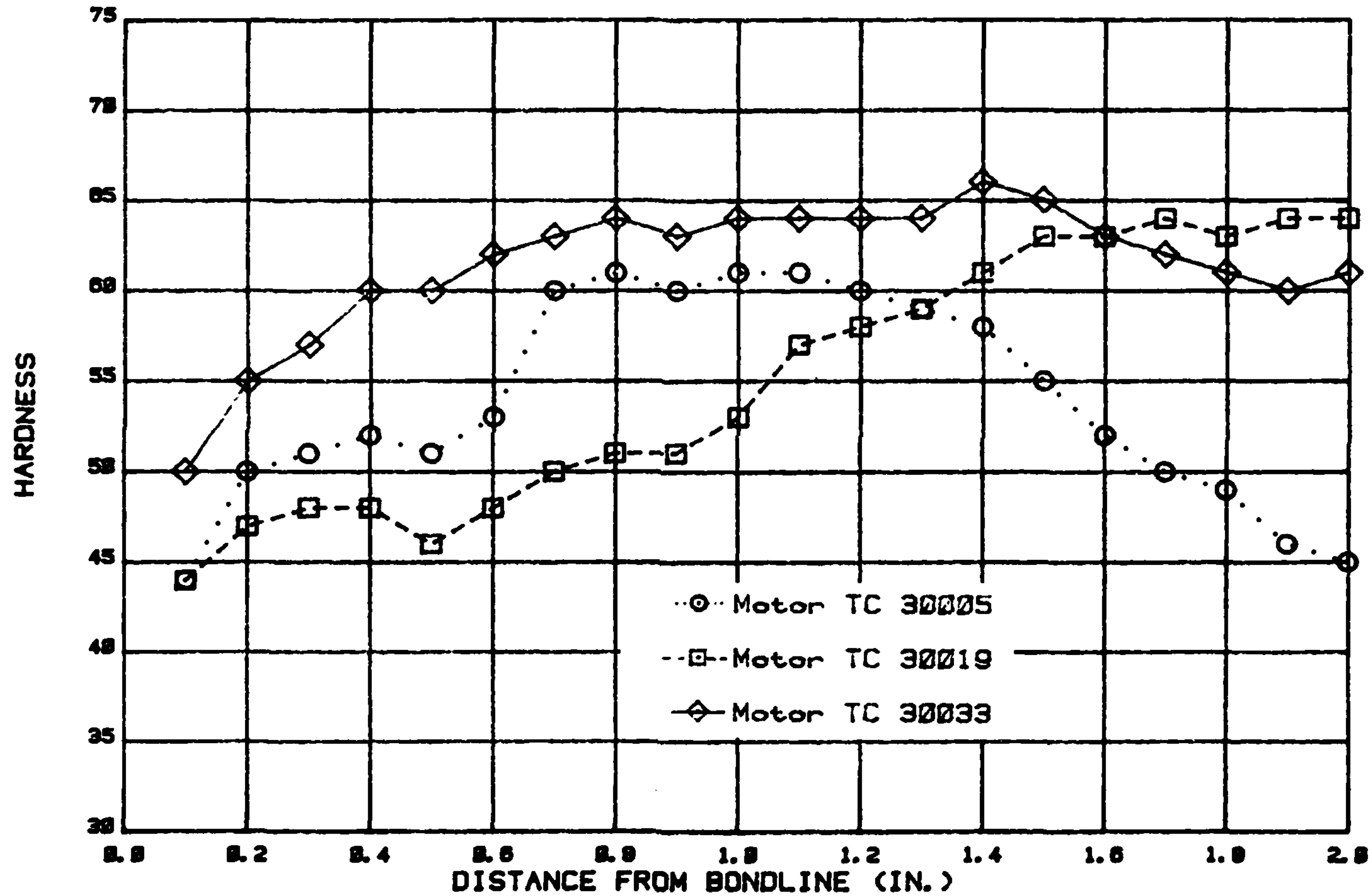


Figure 22. Shore A Hardness Gradient of ANB-3066 Propellant in the Forward Flap, Area A

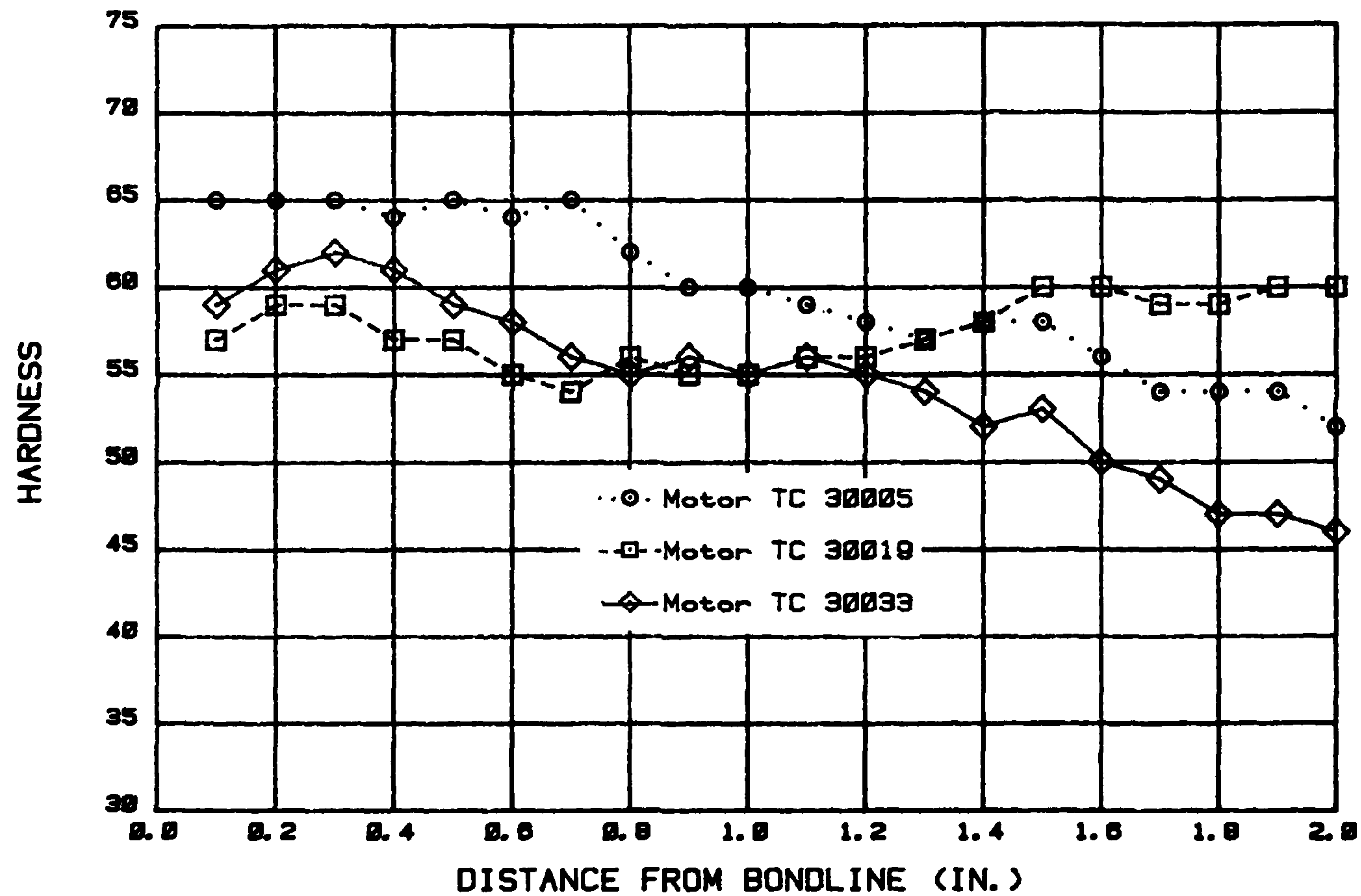


Figure 23. Shore A Hardness Gradient of ANB-3066 Propellant in the Forward Flap, Area B

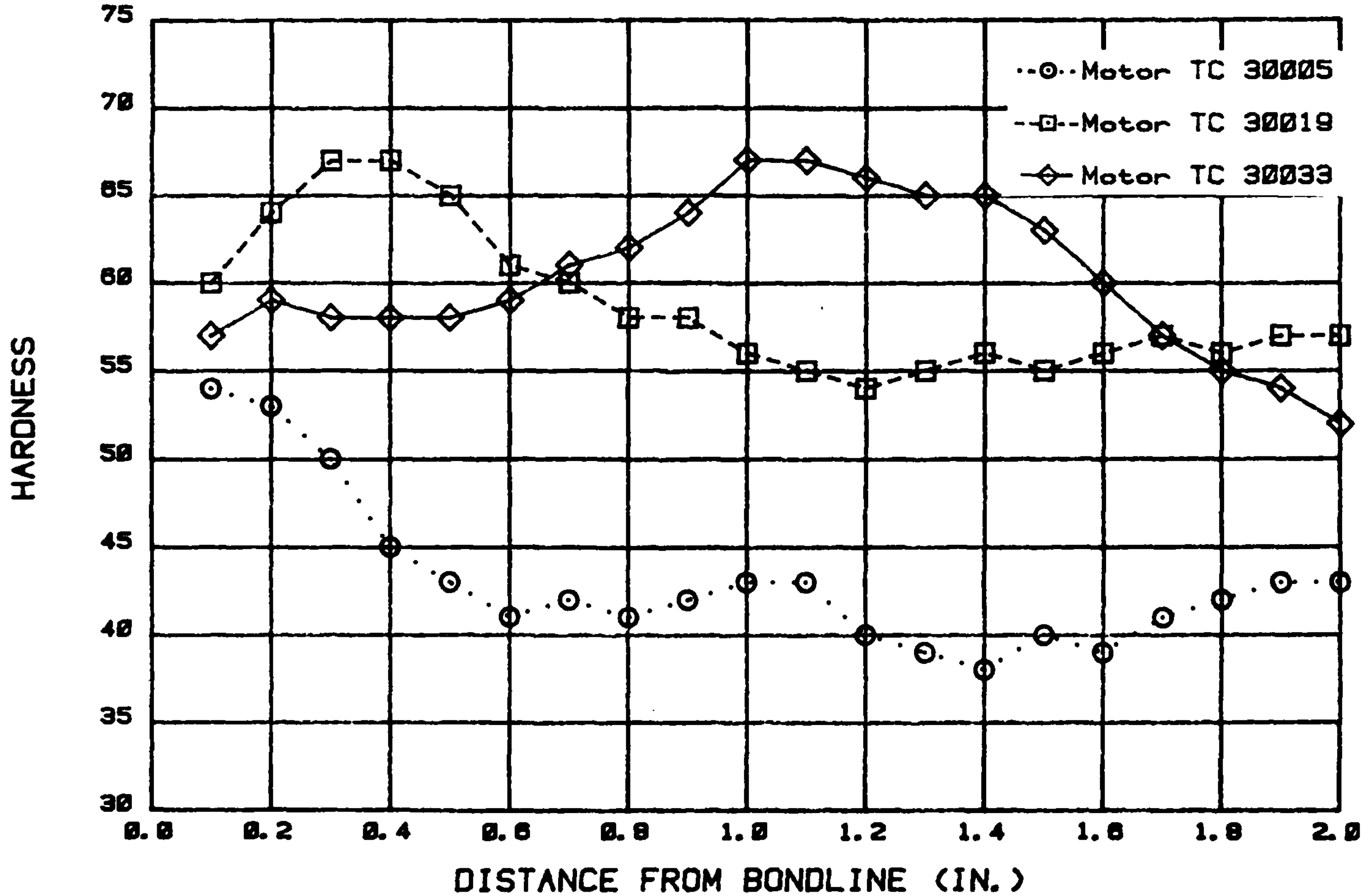


Figure 24. Shore A Hardness Gradient of ANB-3066 Propellant in the Forward Flap, Area C

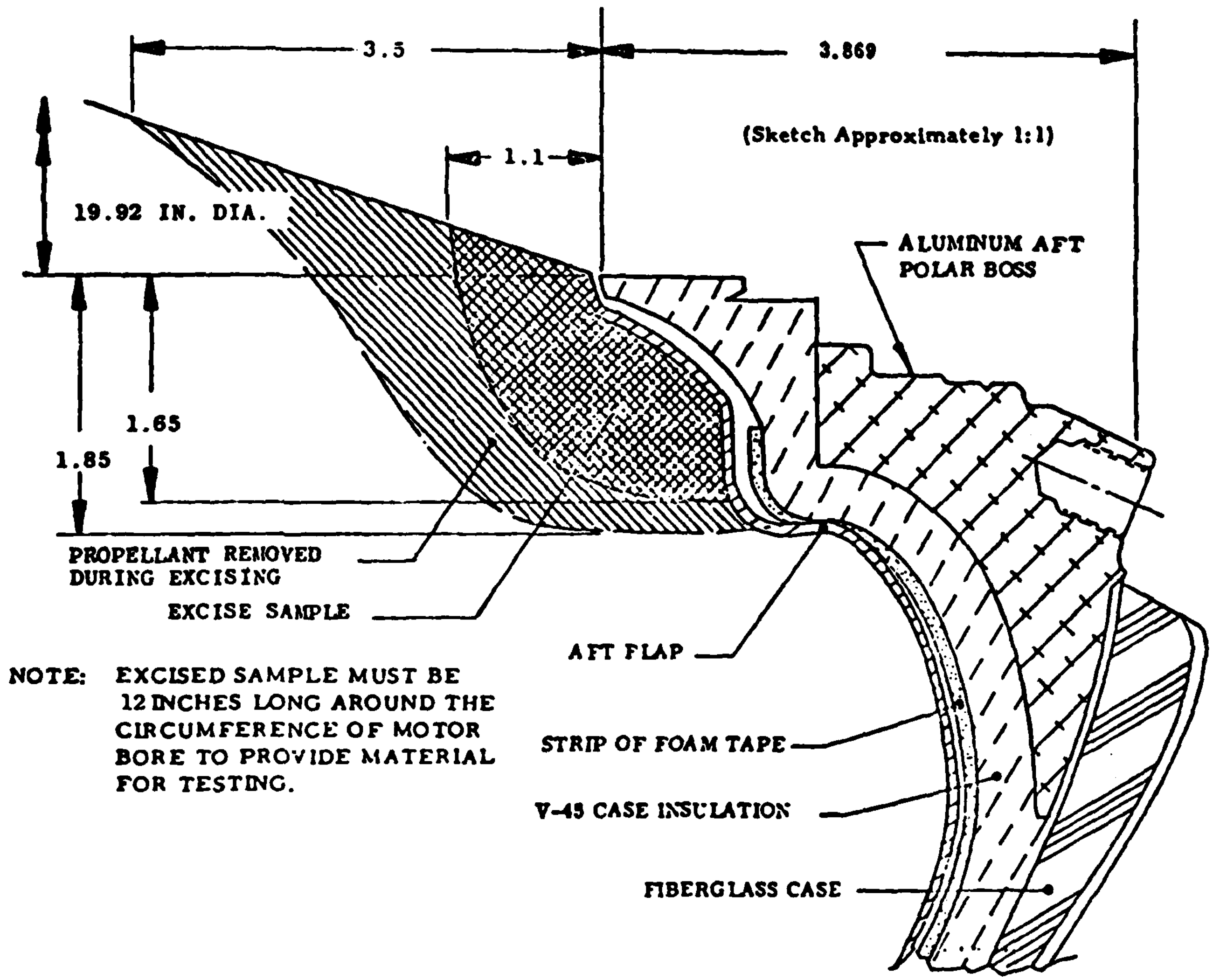


Figure 25. Excixe Sample Diagram

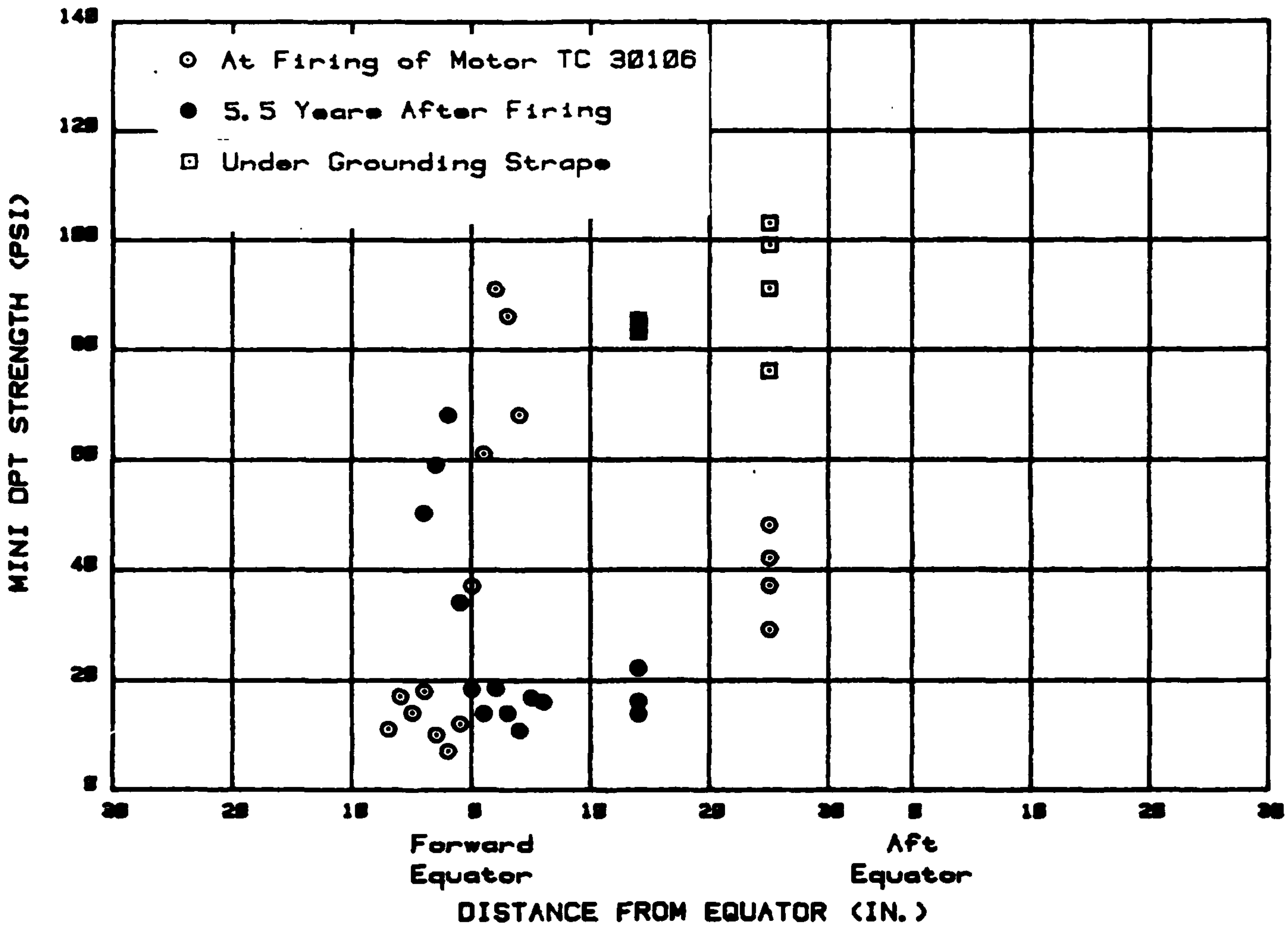


Figure 26. Liner Bond Tensile Strength at Various Motor Locations: Motor TC 30050 Segments at Time of Firing of Motor TC 30106 and 5.5 Years Later

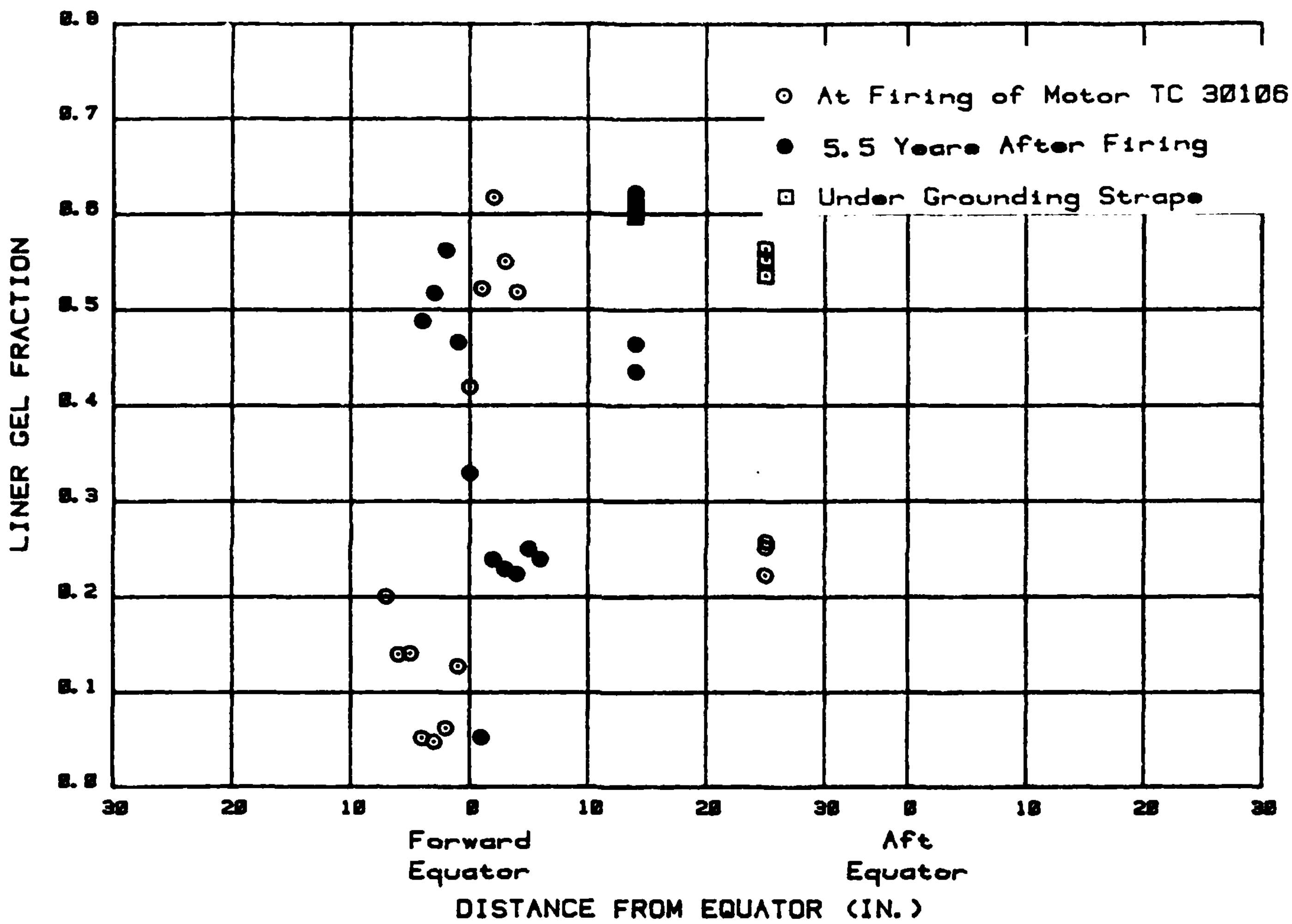


Figure 27. Liner Gel Fraction at Various Motor Locations: Motor TC 30050 Segments at Time of Firing of Motor TC 30106 and 5.5 Years Later

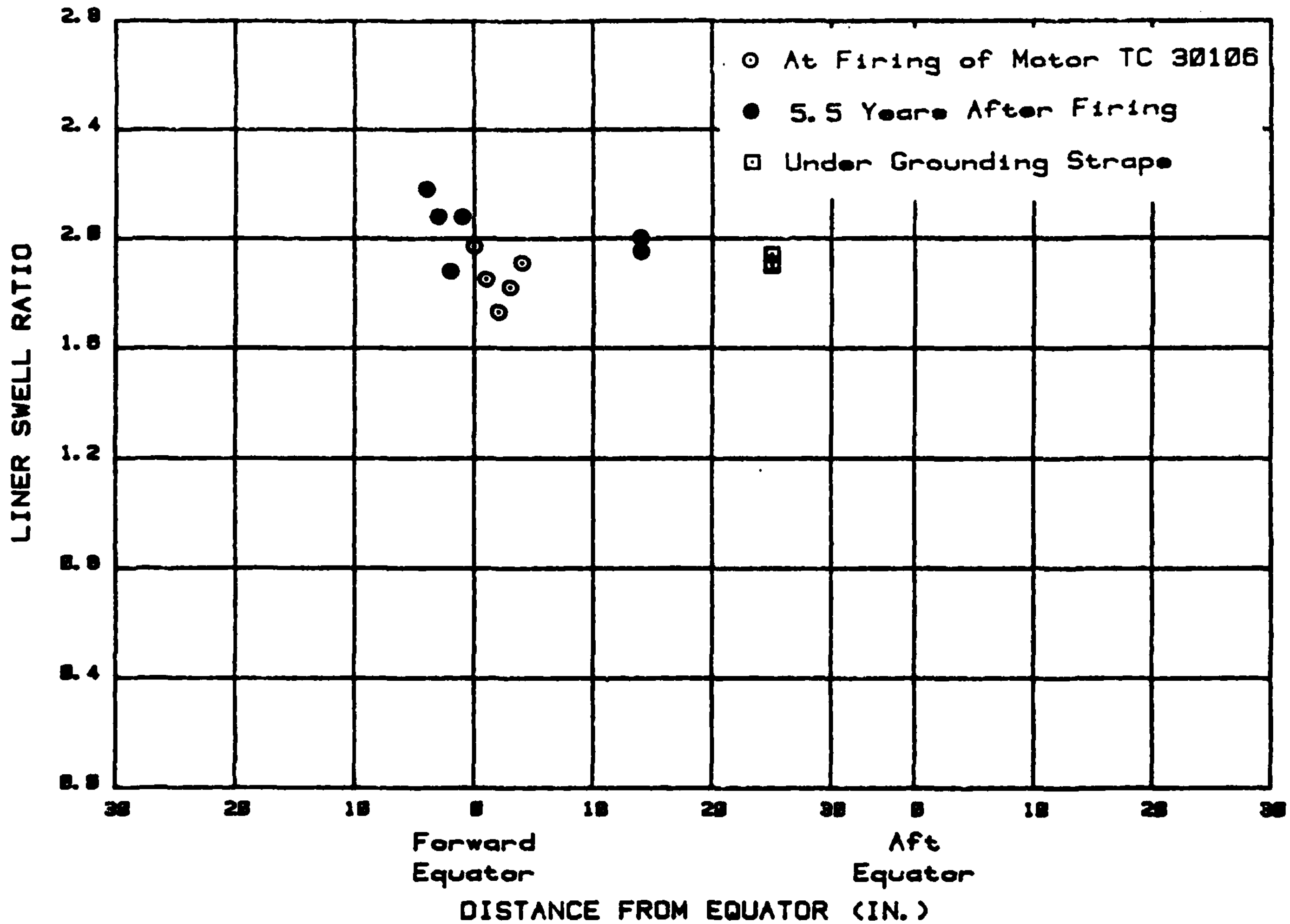


Figure 28. Liner Swell Ratio at Various Motor Locations: Motor TC 30050 Segments at Time of Firing of Motor TC 30106 and 5.5 Years Later

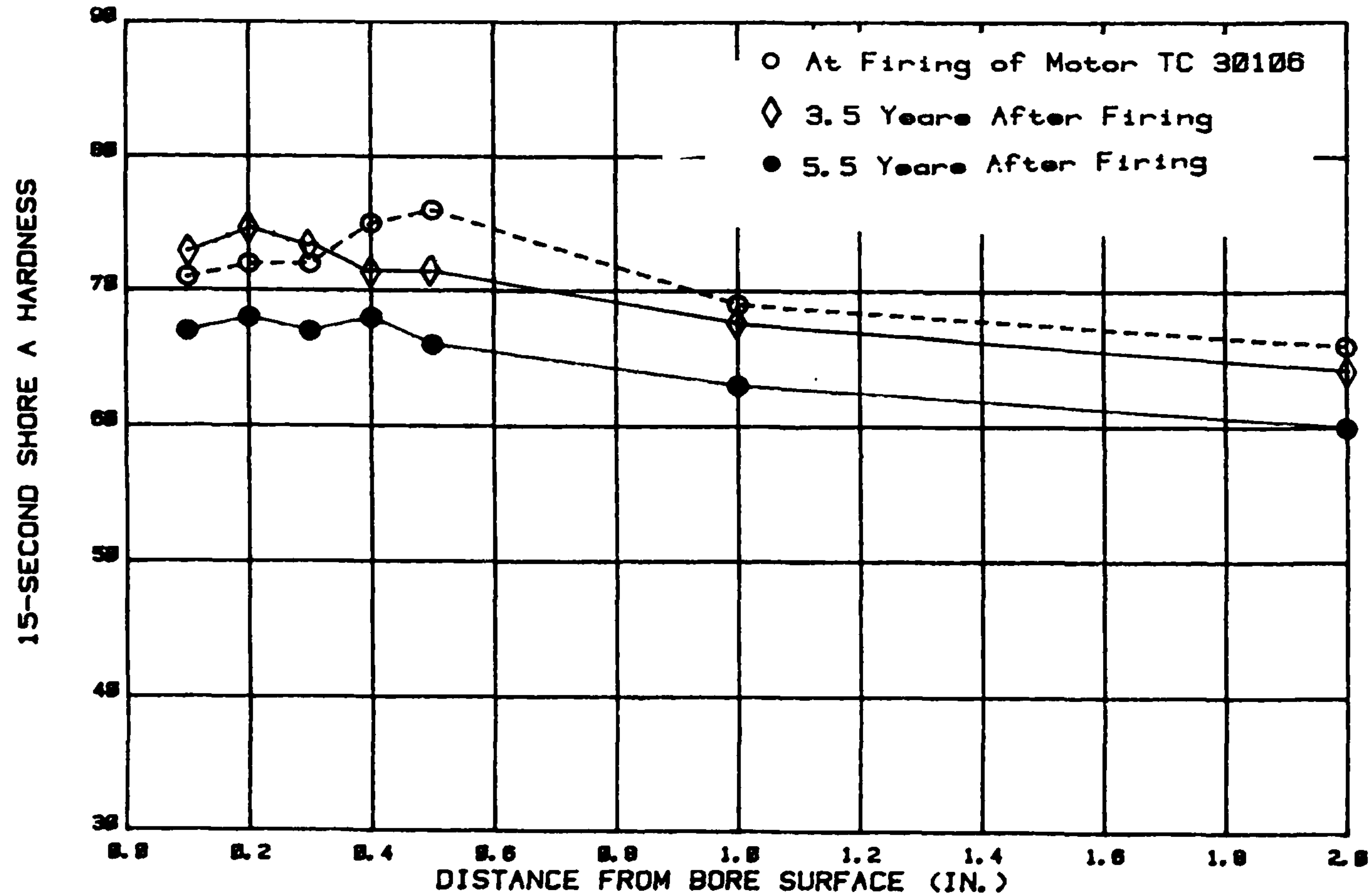


Figure 29. Shore A Hardness of Bore Propellant: Motor TC 30050 Segments at Time of Firing of Motor TC 30106 and 5.5 Years Later

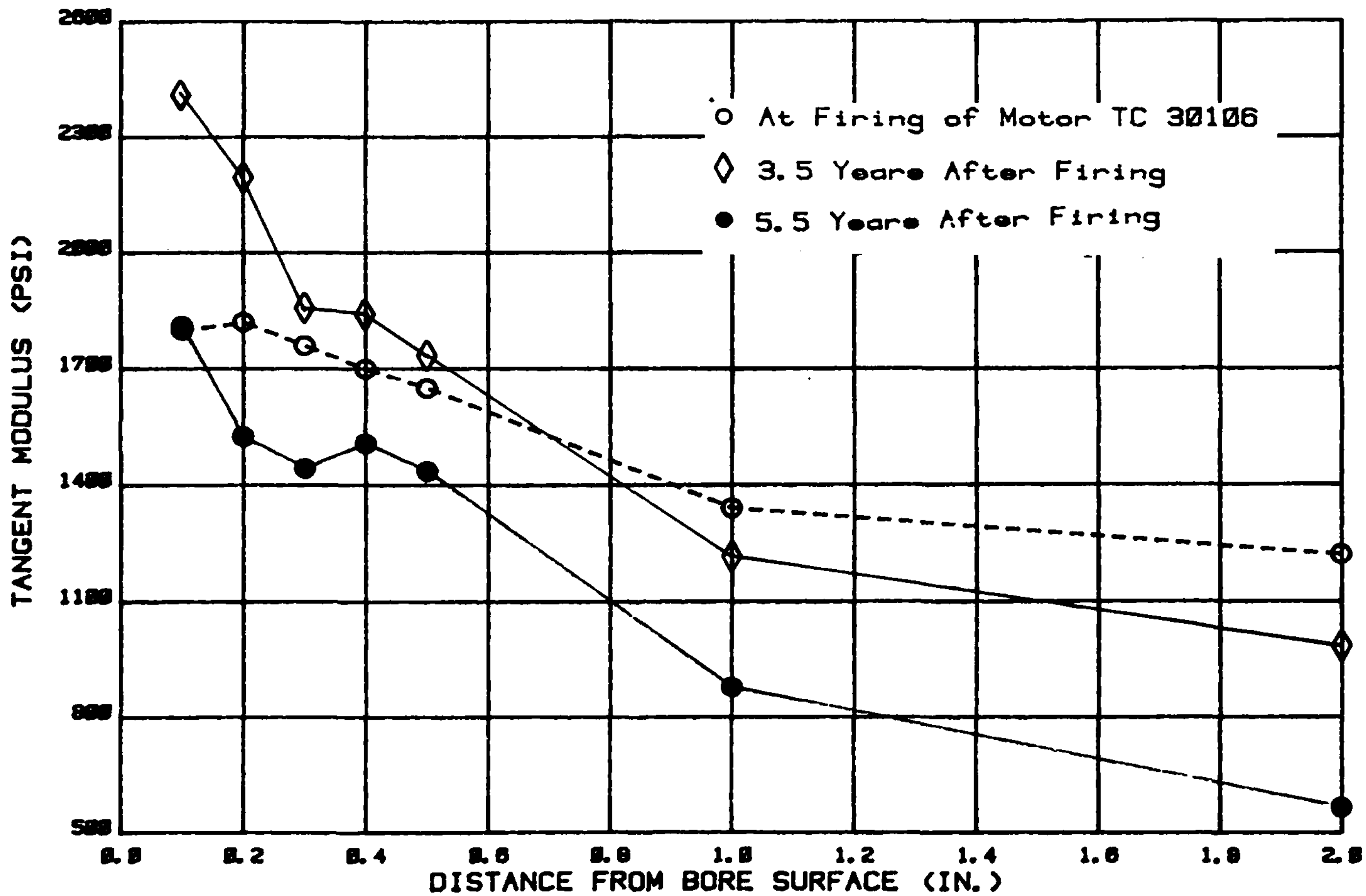


Figure 30. Modulus of Mini Tensile Specimens from Bore Propellant: Motor TC 30050 Segments at Time of Firing of Motor TC 30106 and 5.5 Years Later

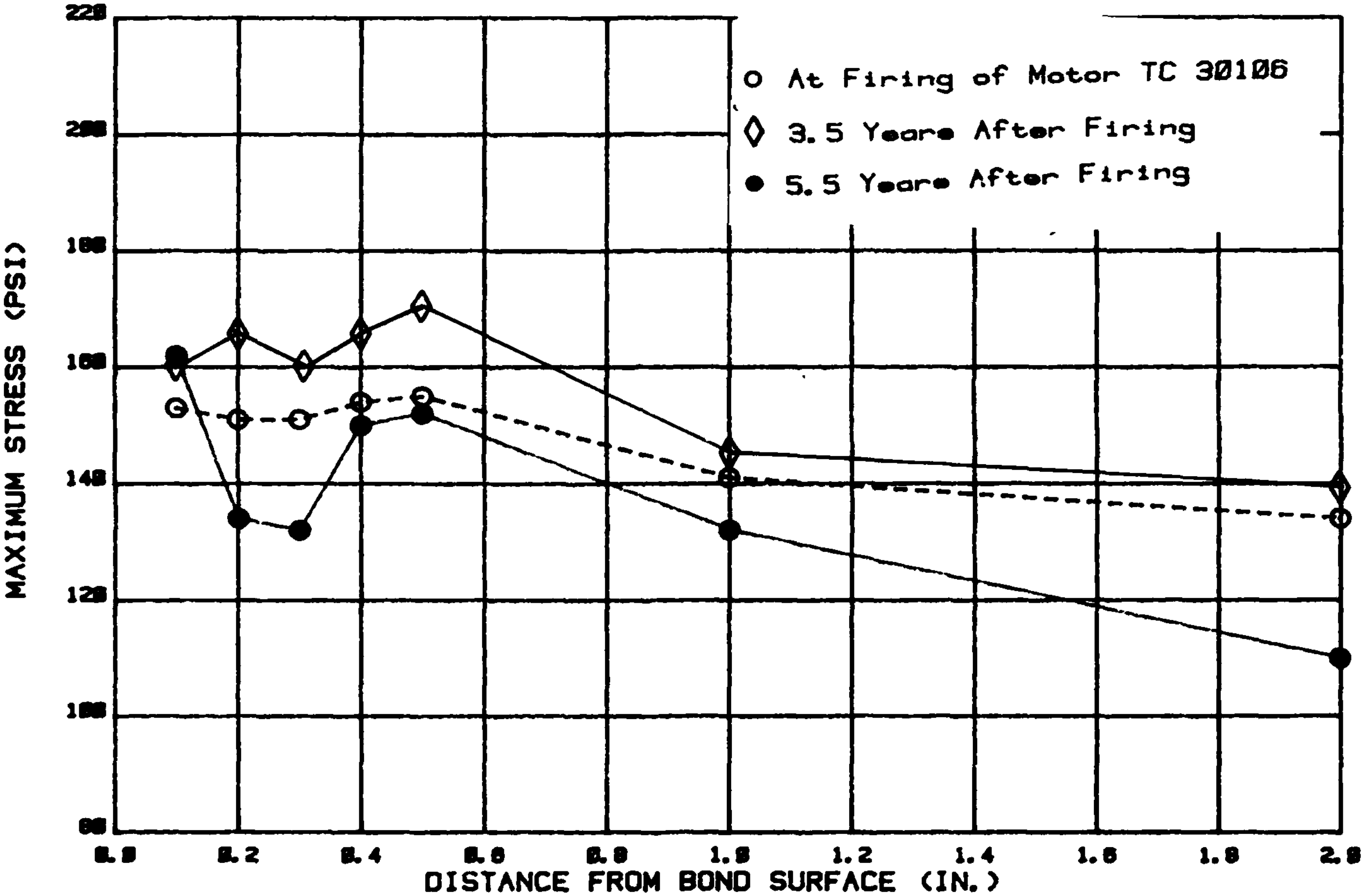


Figure 31. Maximum Stress of Mini Tensile Specimens from Bore Propellant: Motor TC 30050 Segments at Time of Firing of Motor TC 30106, 3.5 and 5.5 Years Later

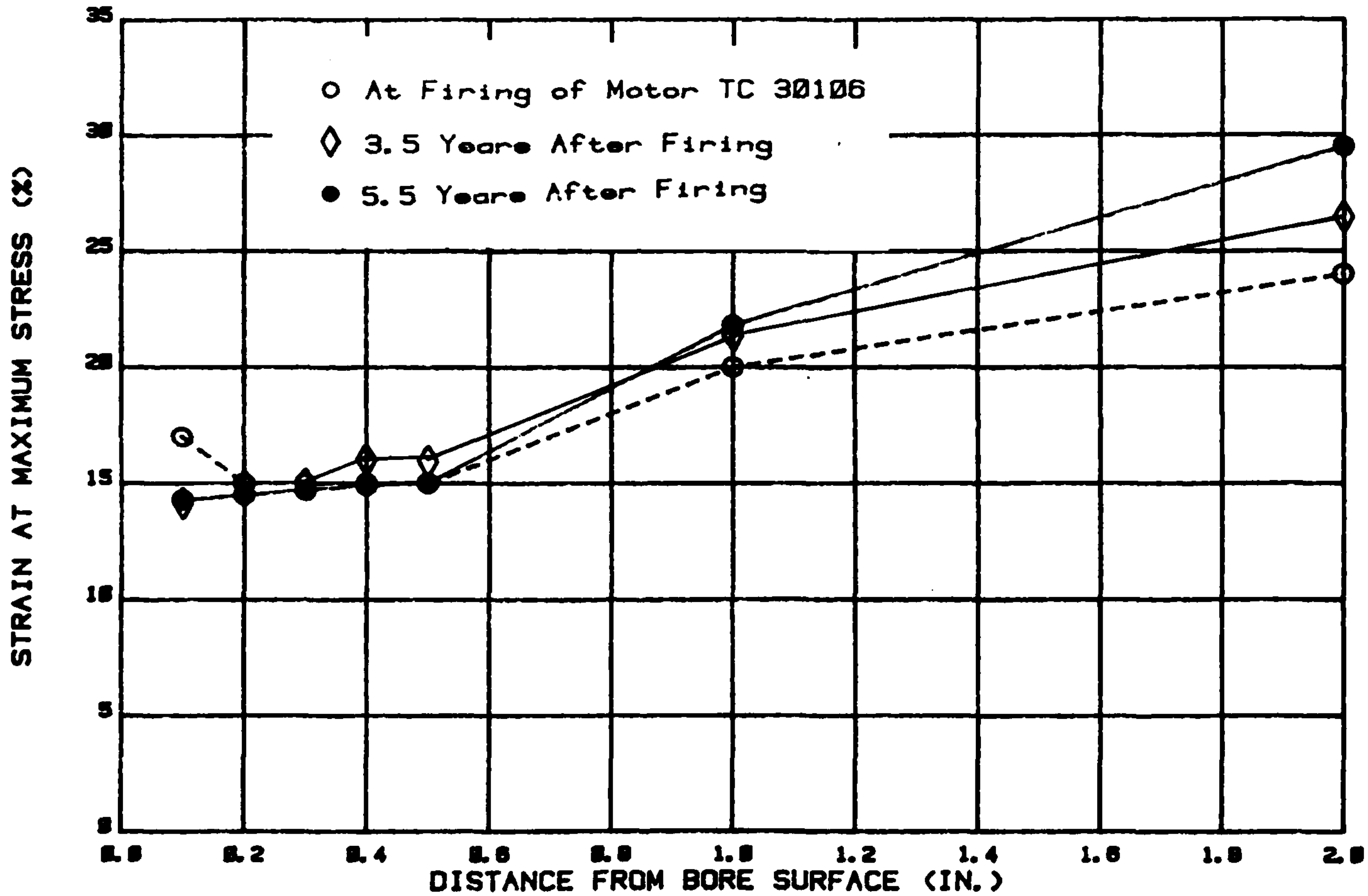


Figure 32. Strain at Maximum Stress of Mini Tensile Specimens from Bore Propellant: Motor TC 30050 Segments at Time of Firing of Motor TC 30106, 3.5 and 5.5 Years Later

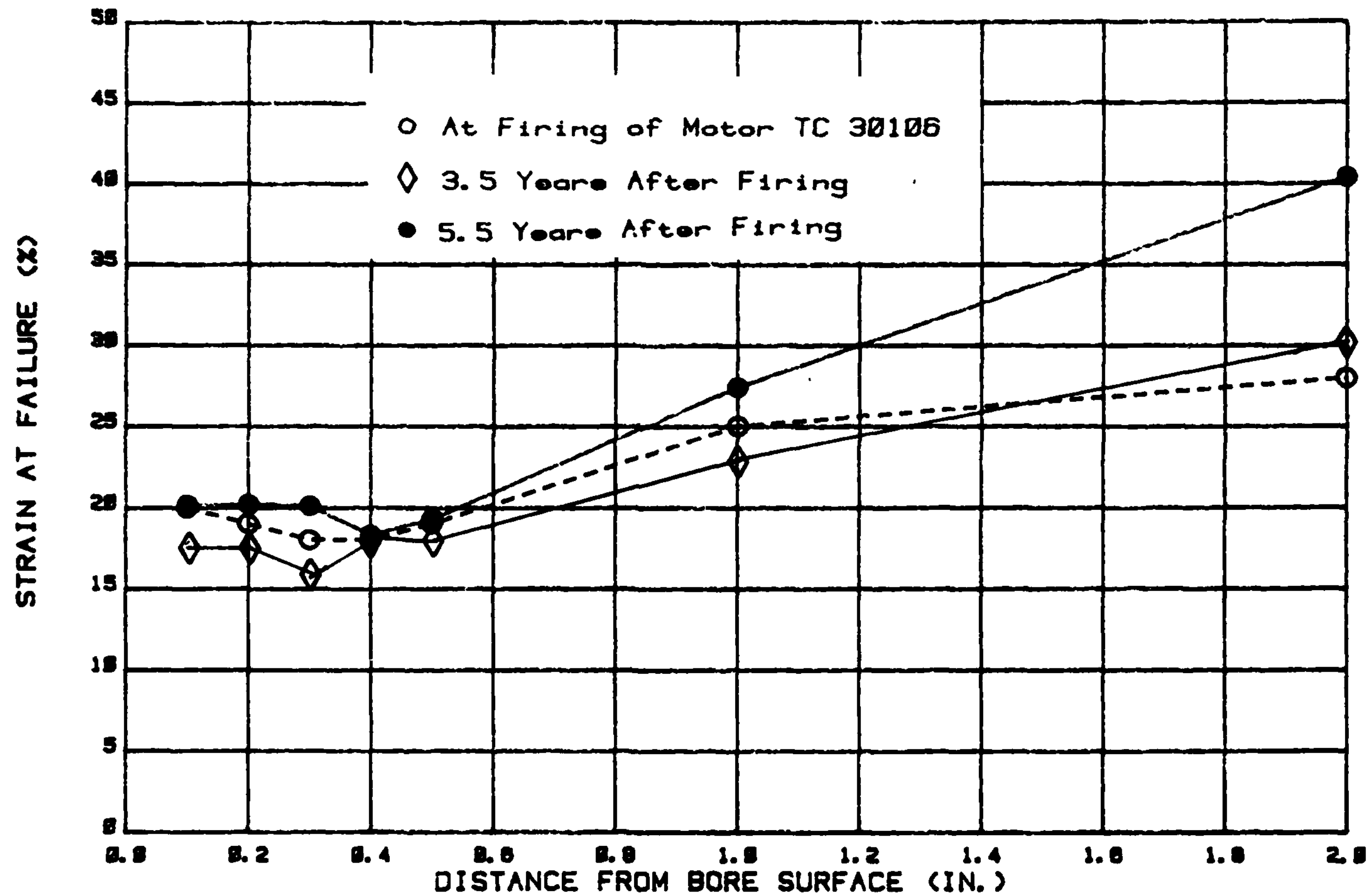


Figure 33. Strain at Failure of Mini Tensile Specimens from Bore Propellant: Motor TC 30050 Segments at Time of Firing of Motor TC 30106, 3.5 and 5.5 Years Later

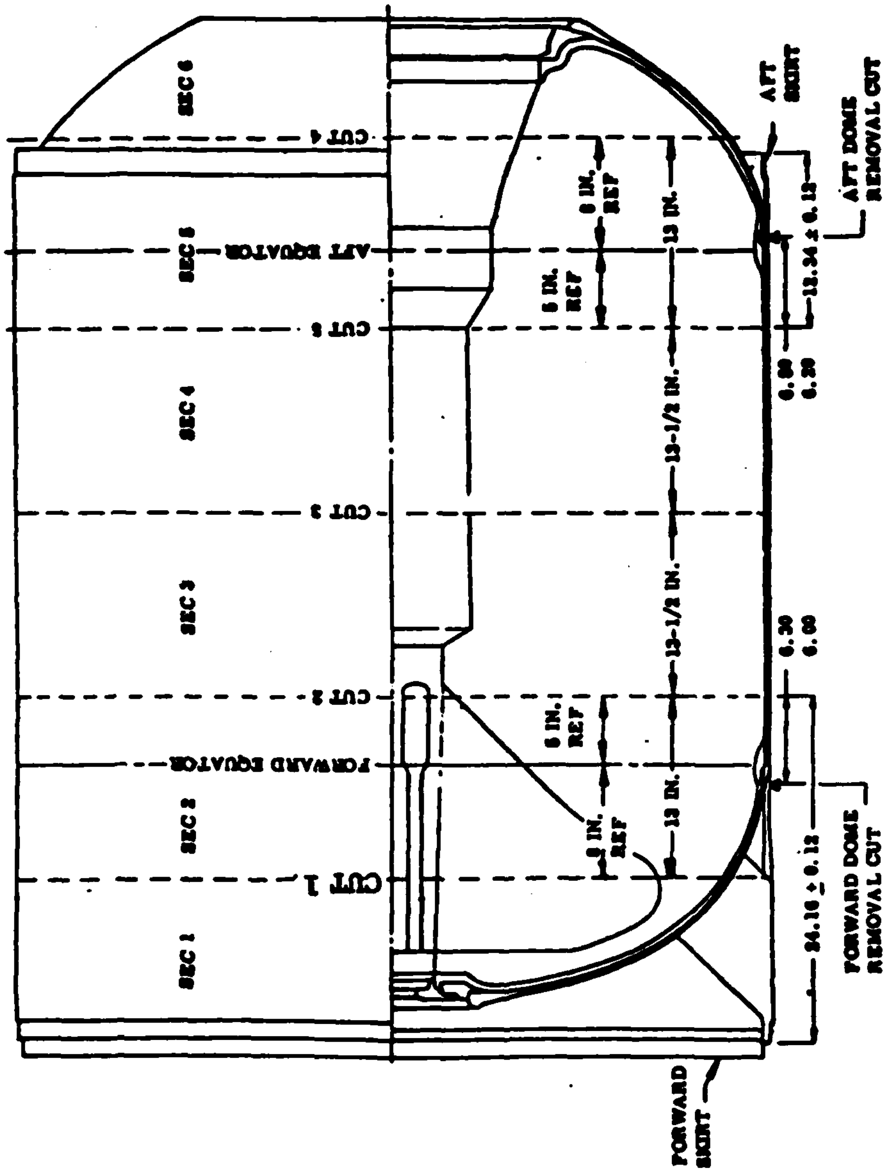


Figure 34. Motor Sectioning Cuts

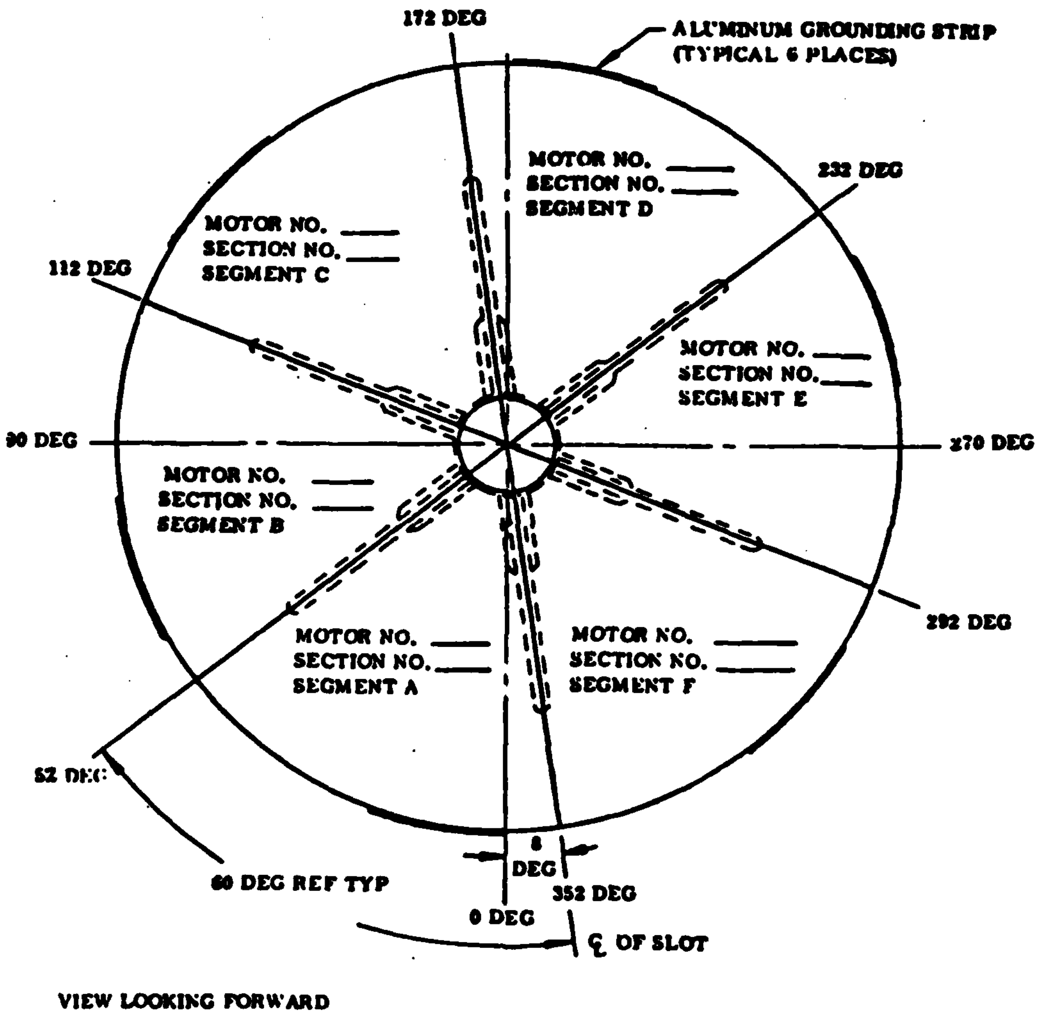


Figure 35. Segment Cuts for Section 1

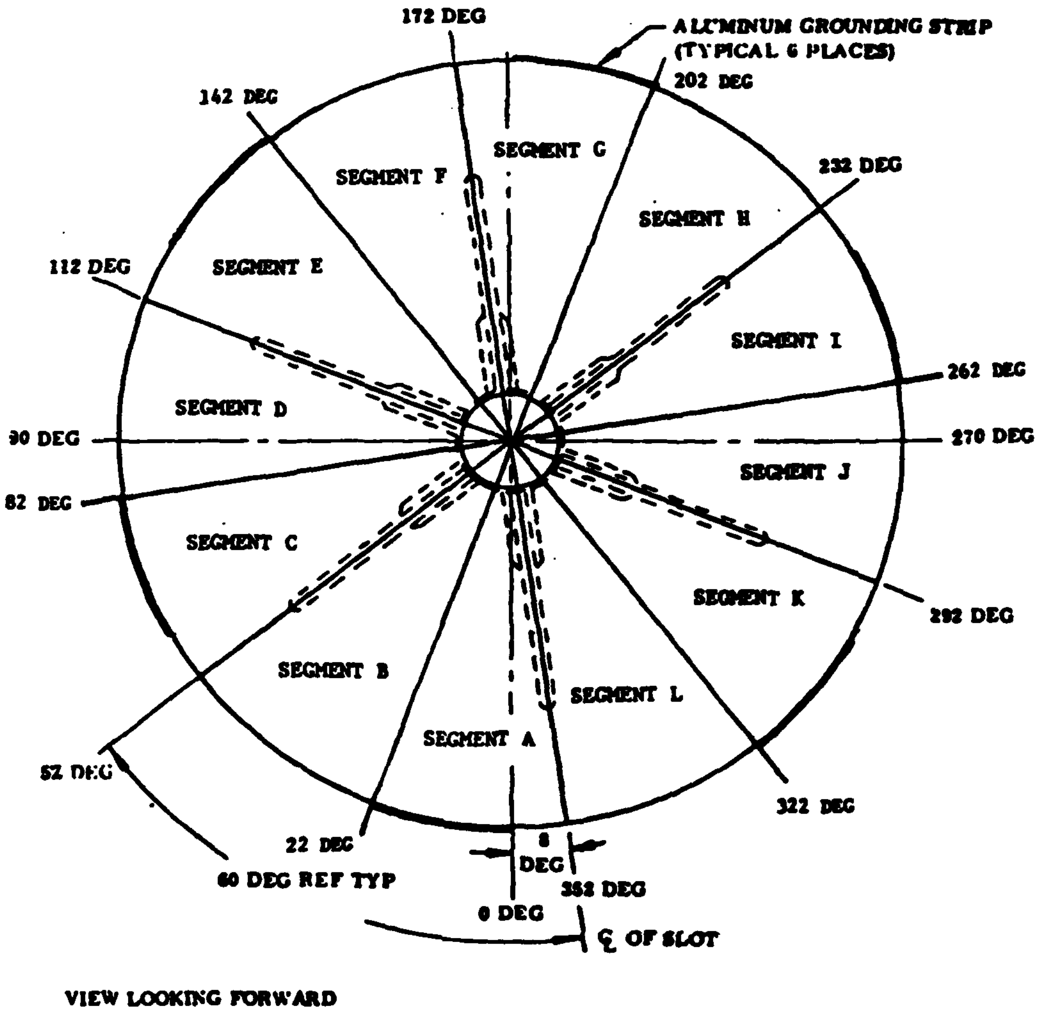


Figure 36. Segment Cuts for Section 2

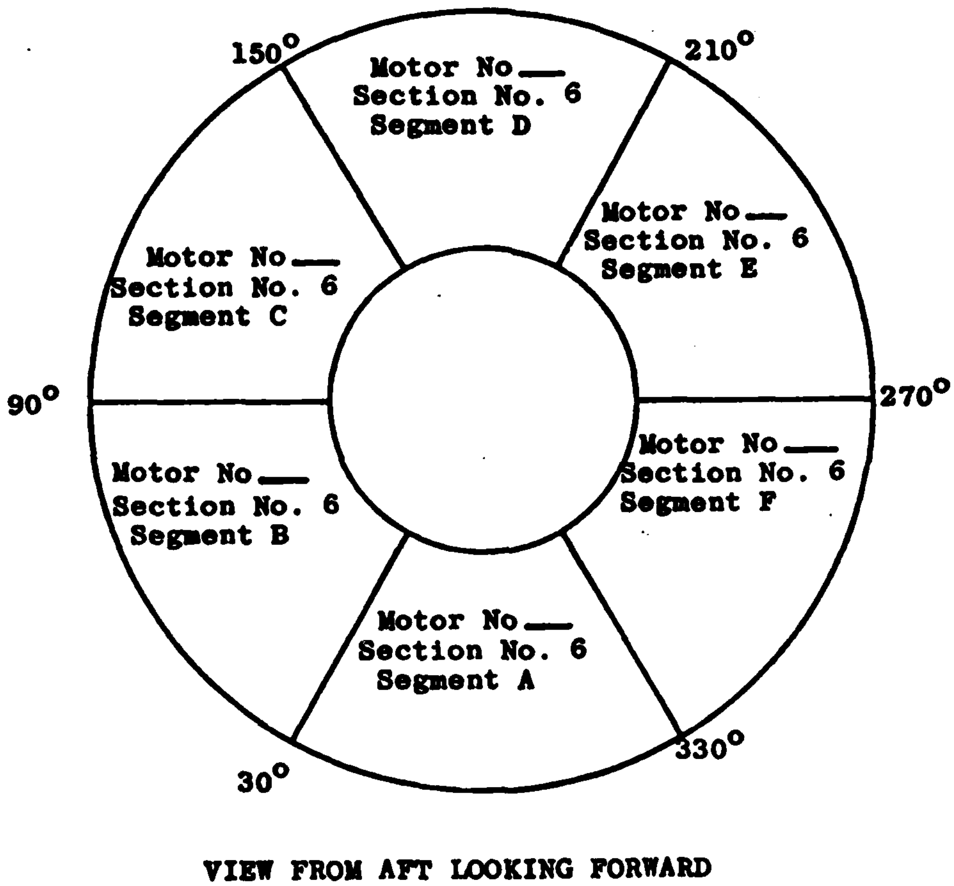
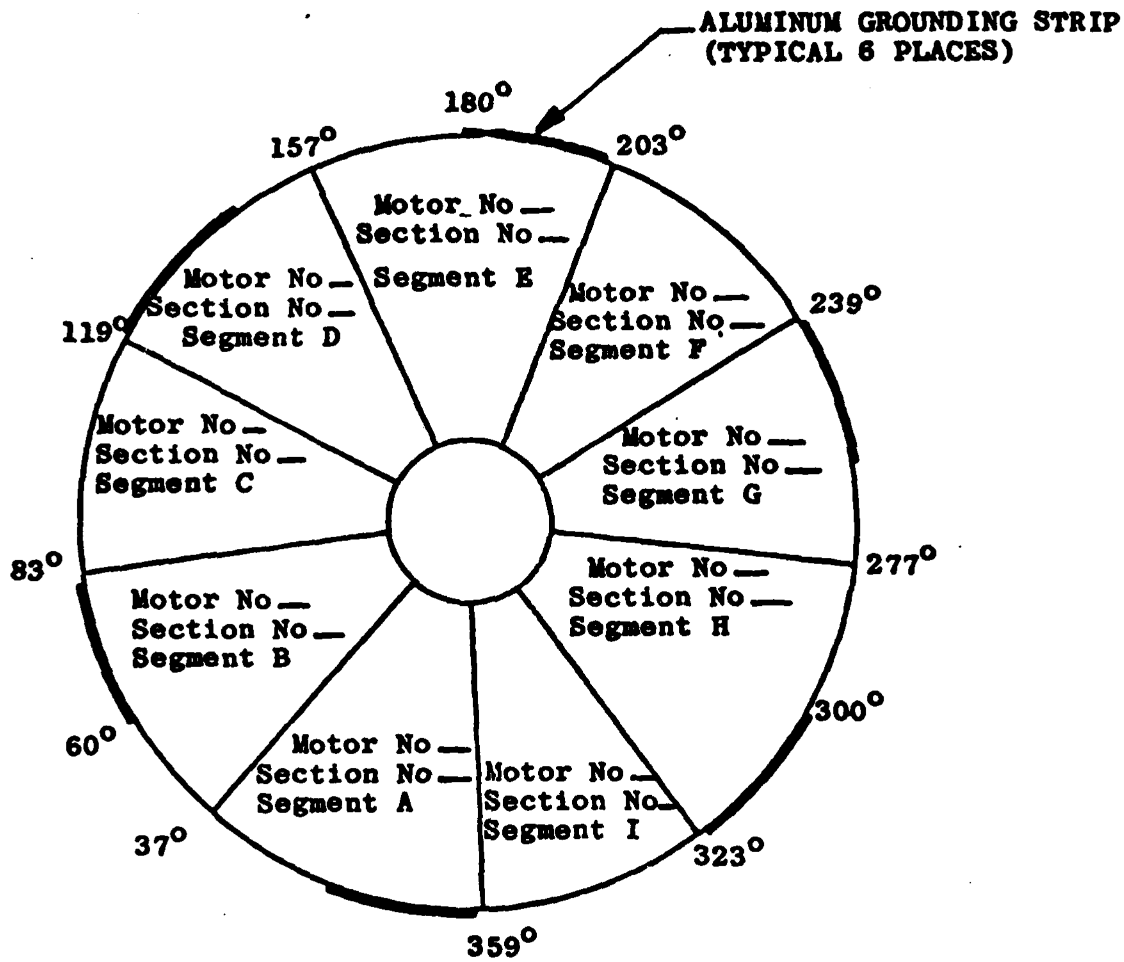
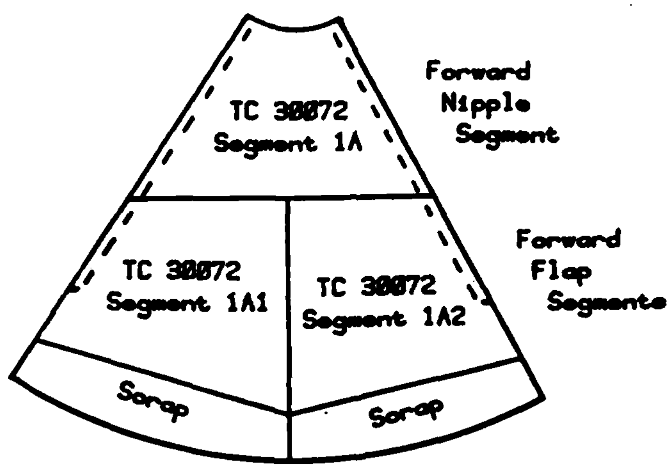


Figure 37. Segment Cuts for Sections 3, 4, and 5



VIEW FROM AFT LOOKING FORWARD

Figure 38. Segment Cuts for Section 6



VIEW LOOKING AFT

Figure 39. Additional Cutting and Typical Marking of Section 1 Segments

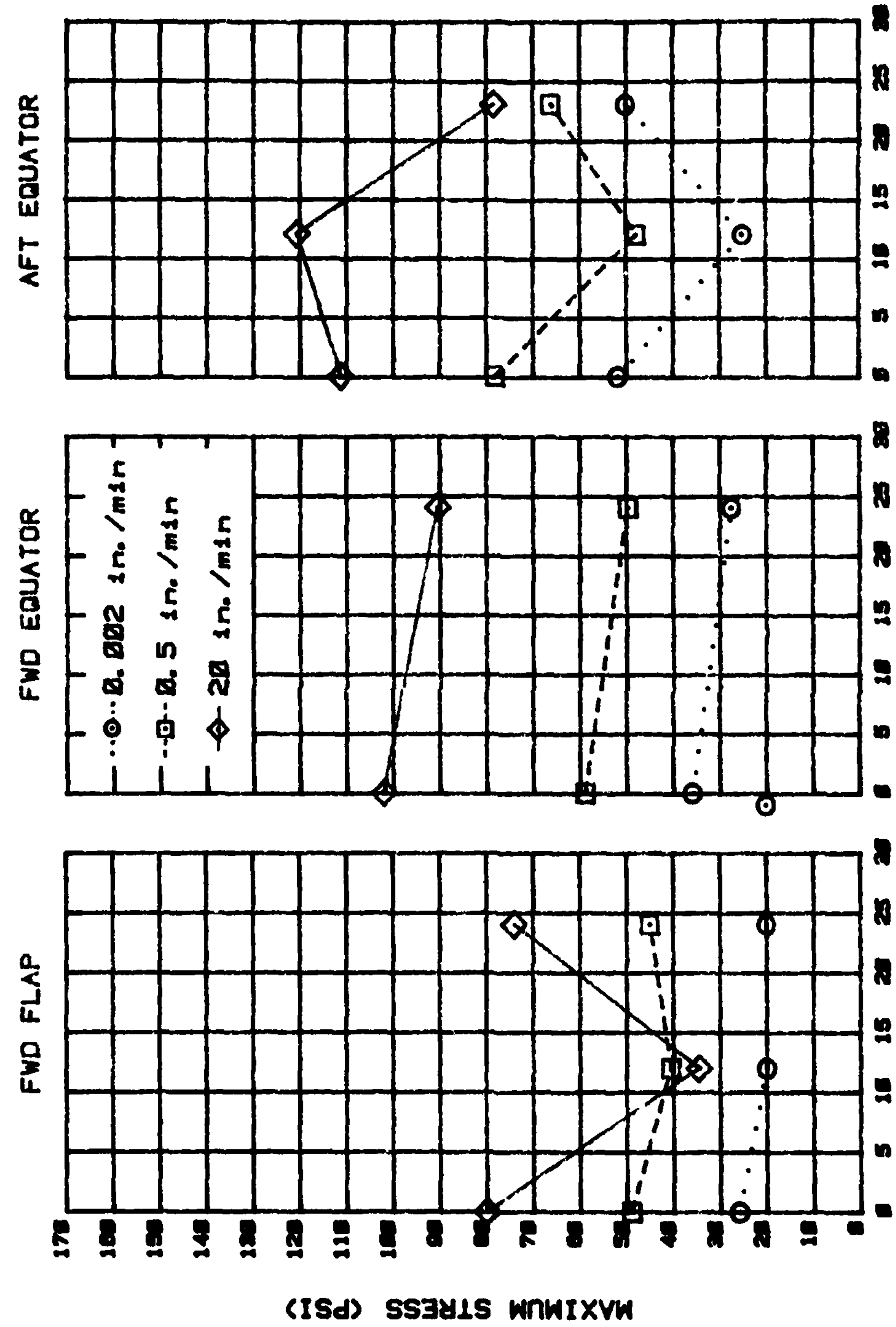


Figure 40. Mini DPT Bond Strength in Motor TC 30072 at Various Motor Locations

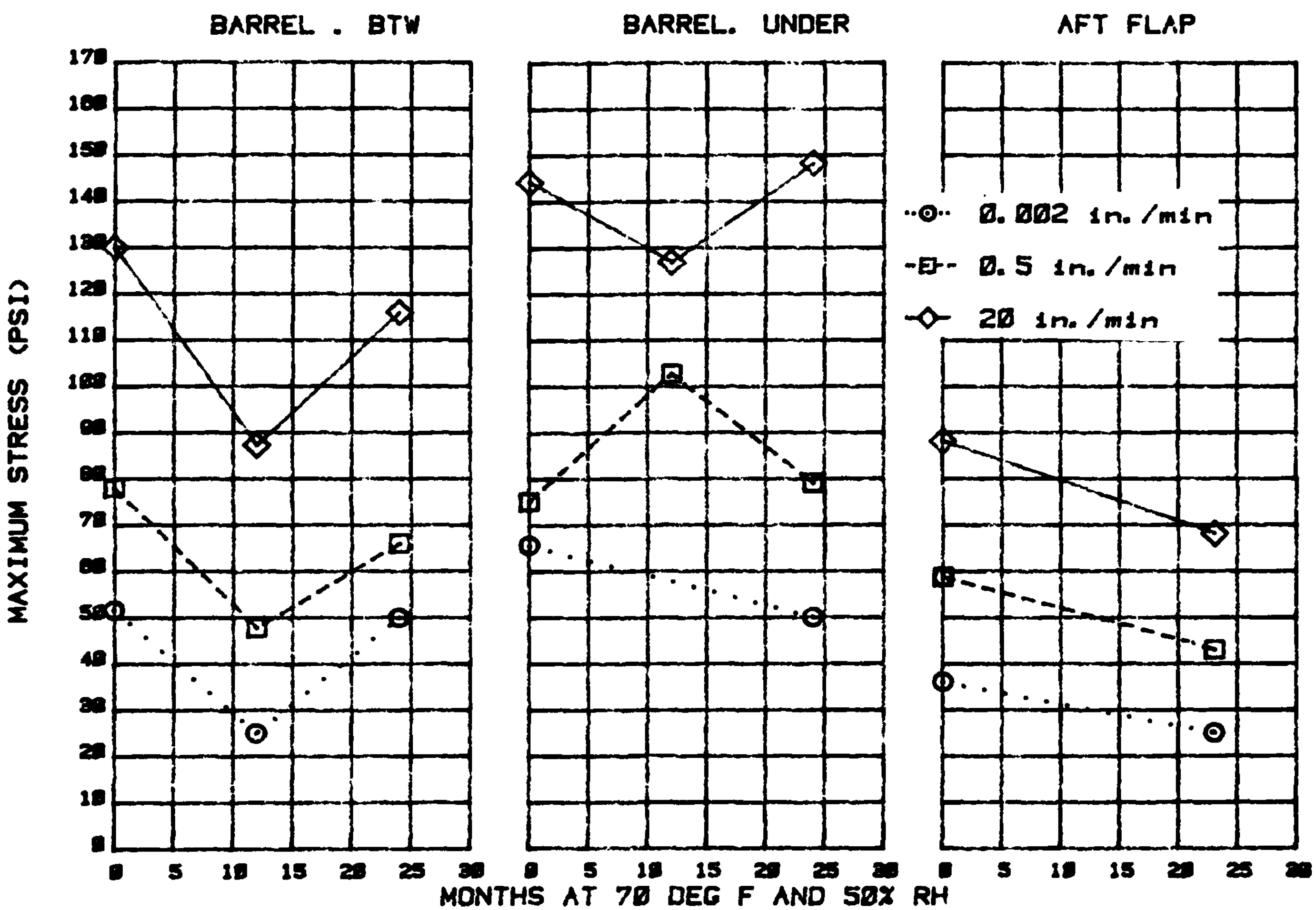


Figure 41. Mini DPT Bond Strength in Motor TC 30072 at Various Motor Locations

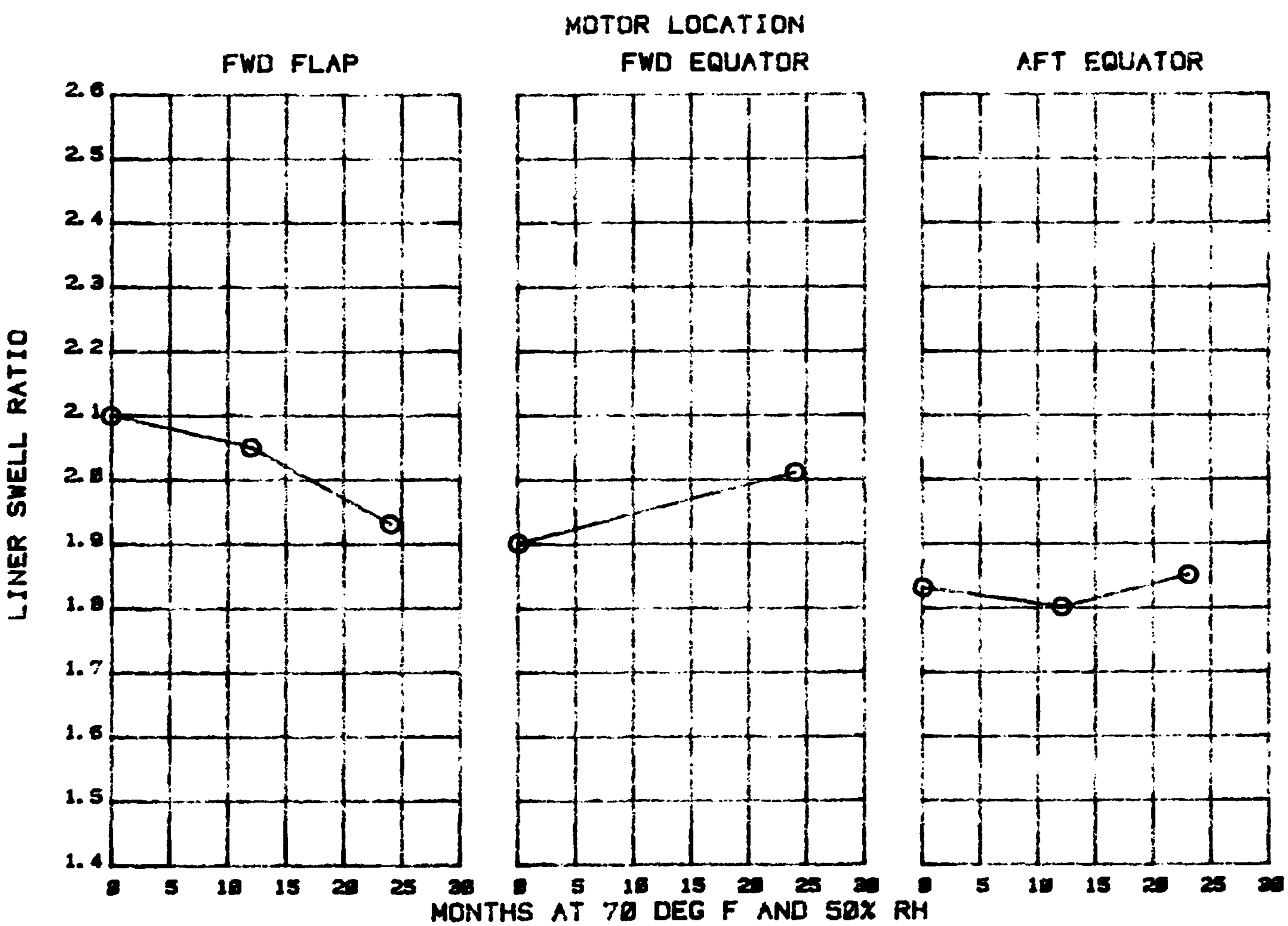


Figure 42. Effect of Storage Conditions Upon Liner Swell Ratio at Various Motor Locations in Motor TC 30072

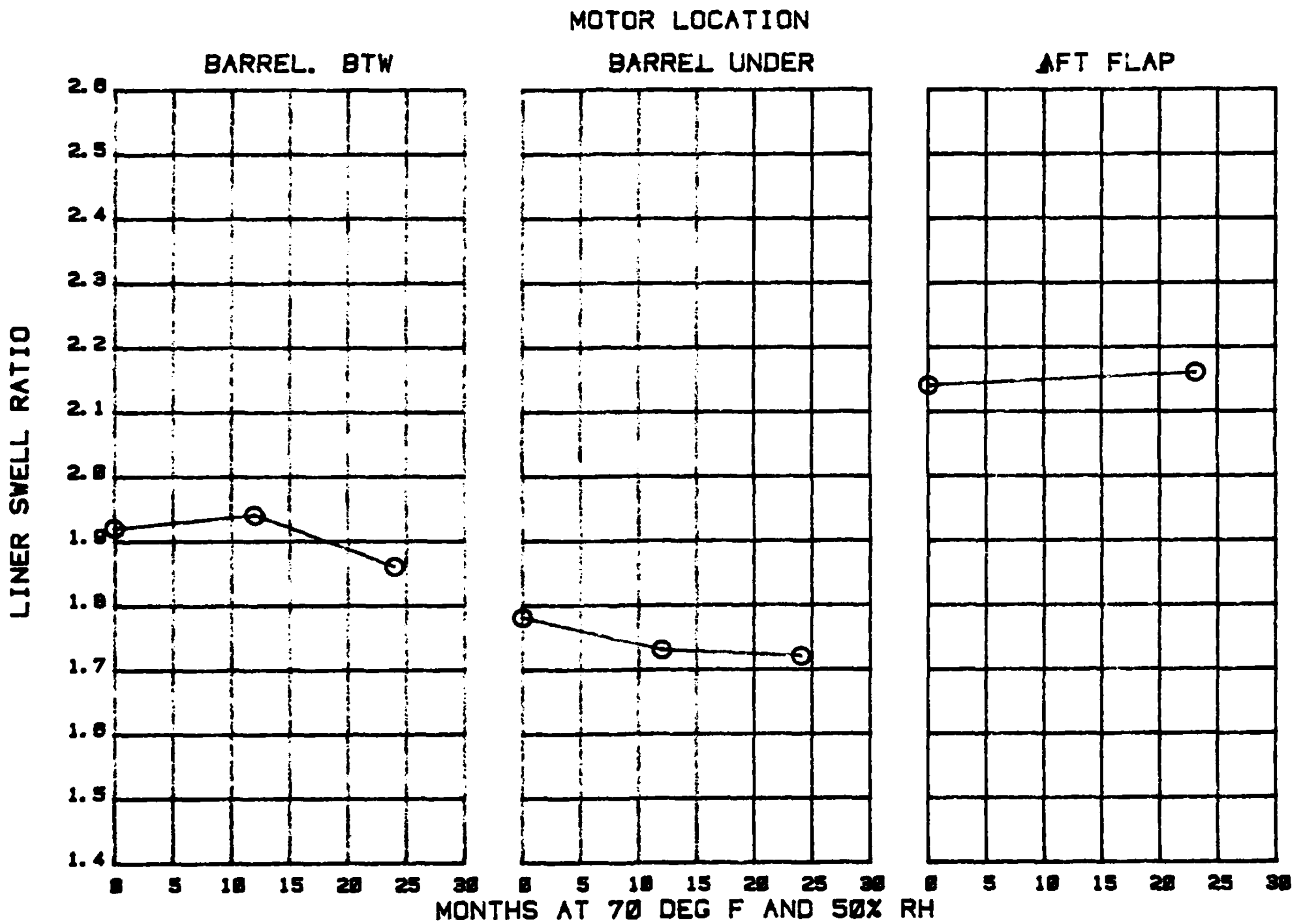


Figure 43. Effect of Storage Conditions Upon Liner Swell Ratio at Various Motor Locations in Motor TC 30072

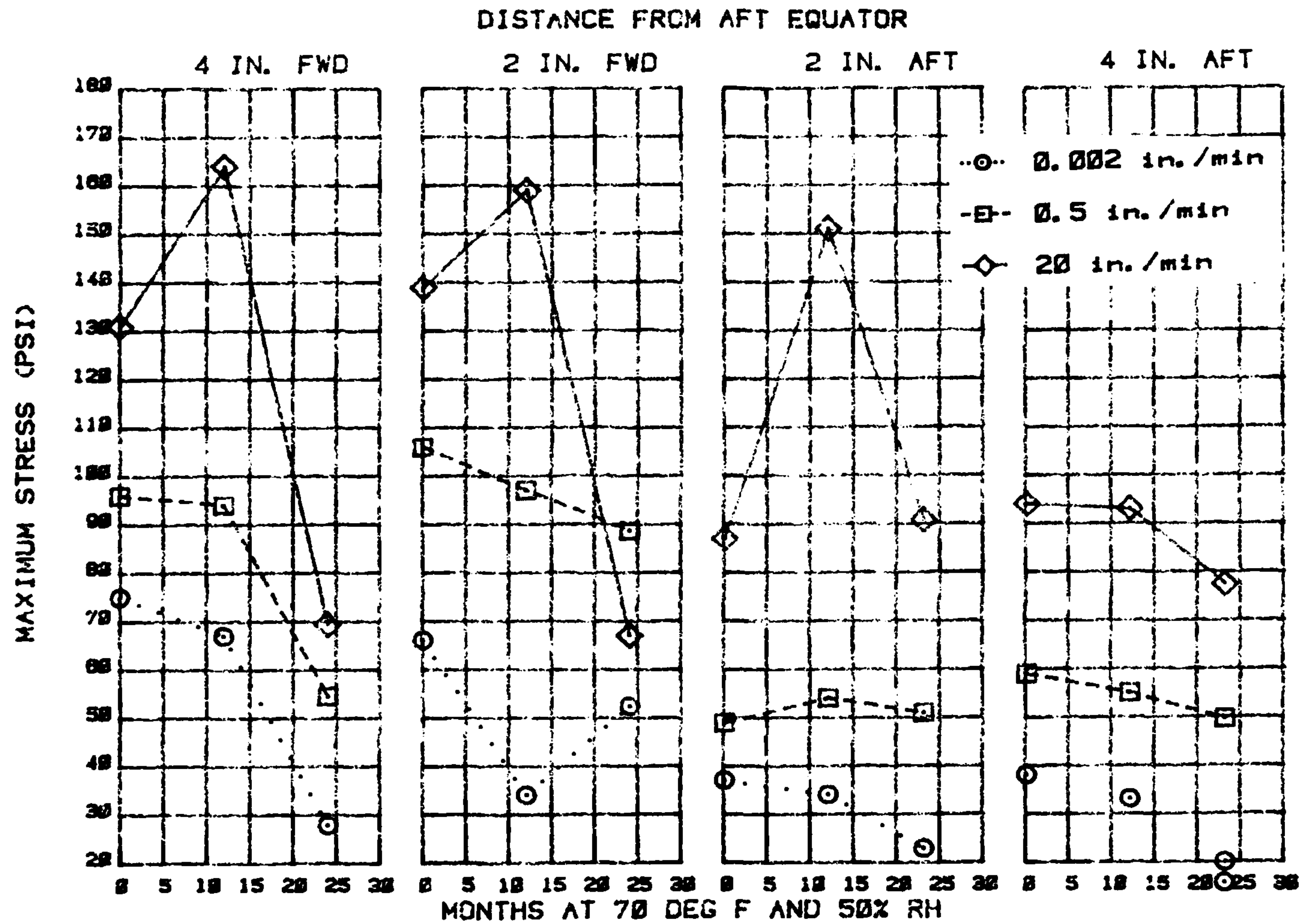


Figure 44. Effect of Storage Conditions Upon Mini DPT Bond Strength Near the Aft Equator of Motor TC 30072

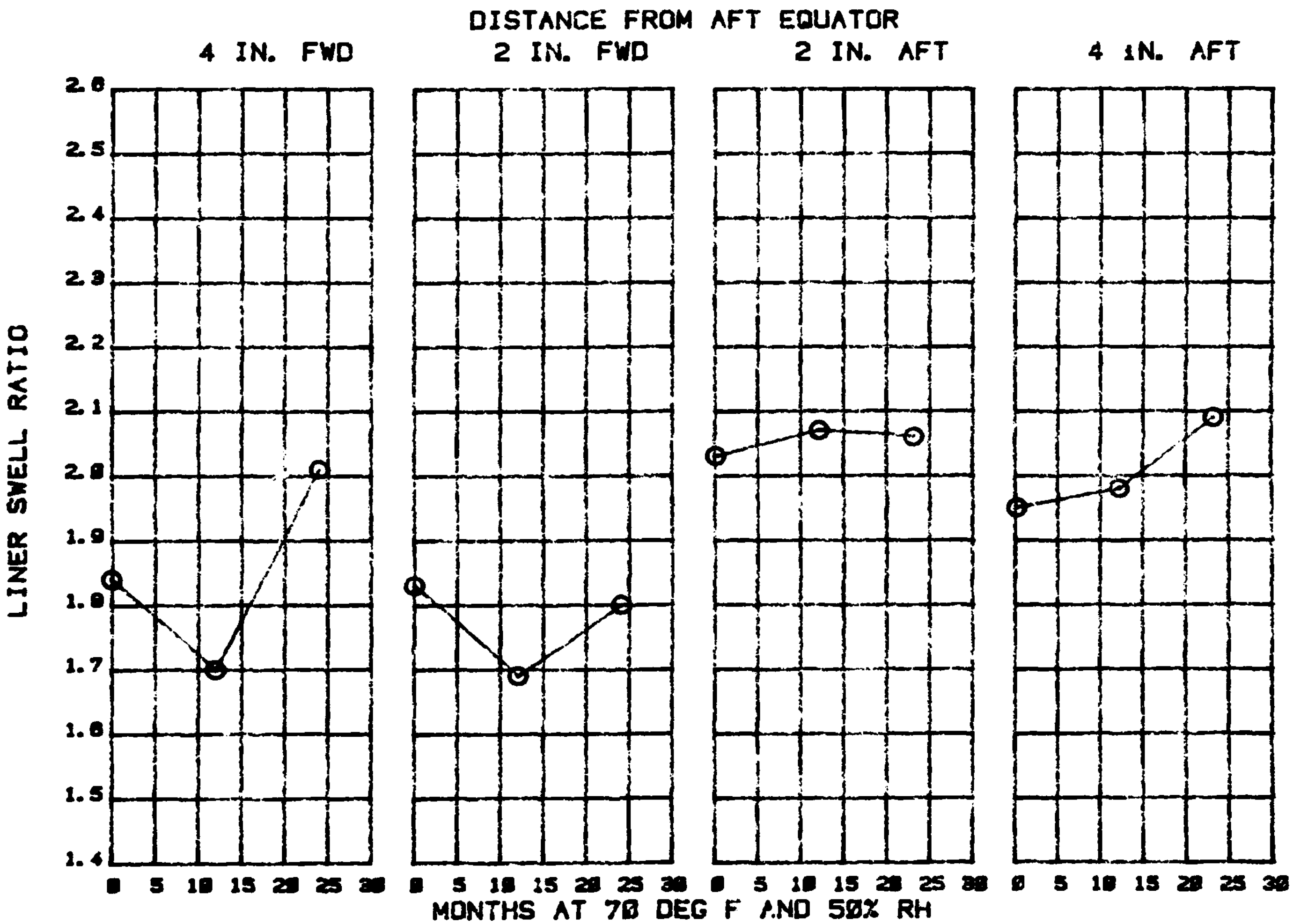


Figure 45. Effect of Storage Conditions Upon Liner Swell Ratio Near the Aft Equator of Motor TC 30072

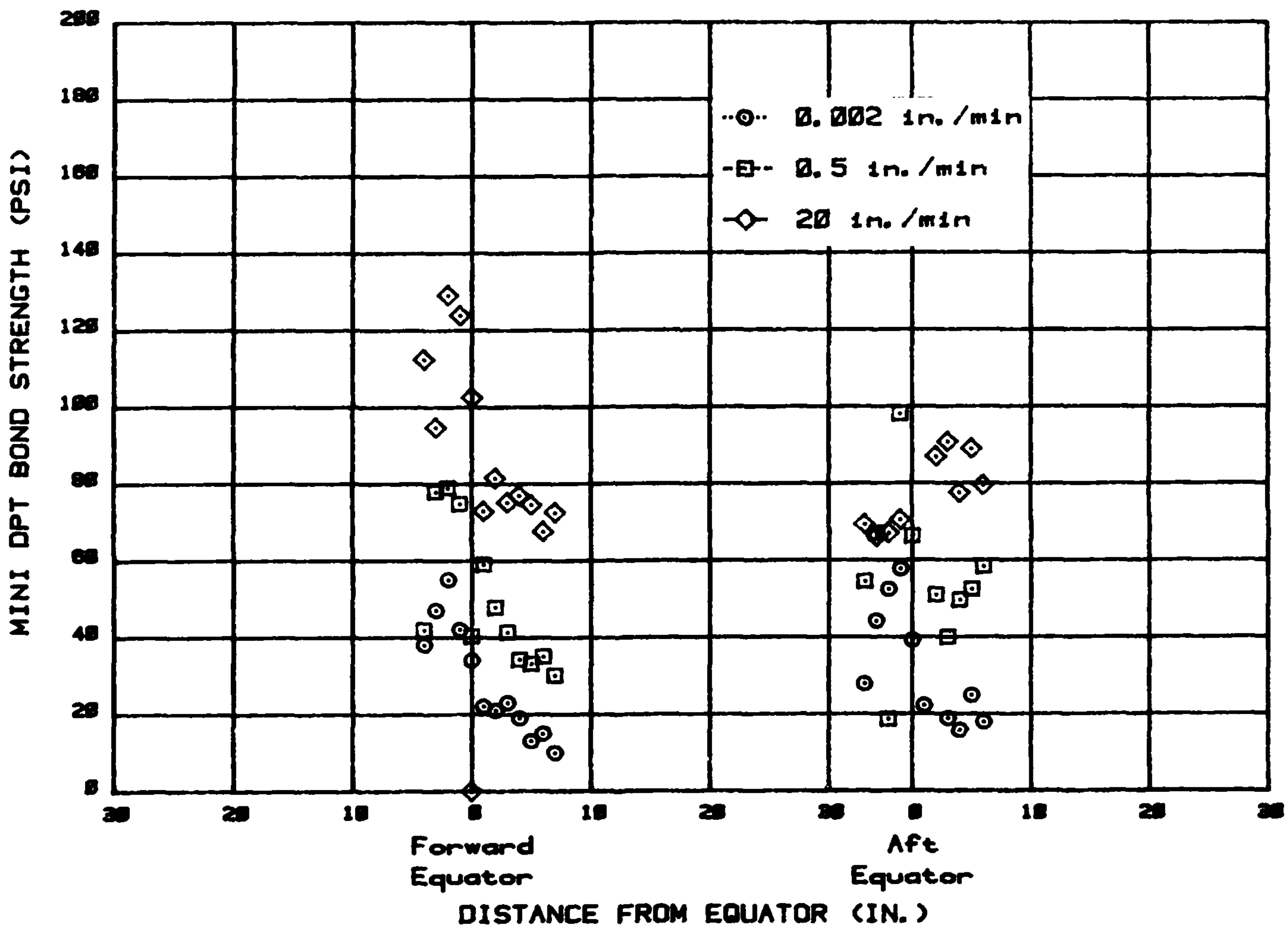


Figure 46. Mini DPT Bond Strength at Various Motor Locations in Motor TC 30072

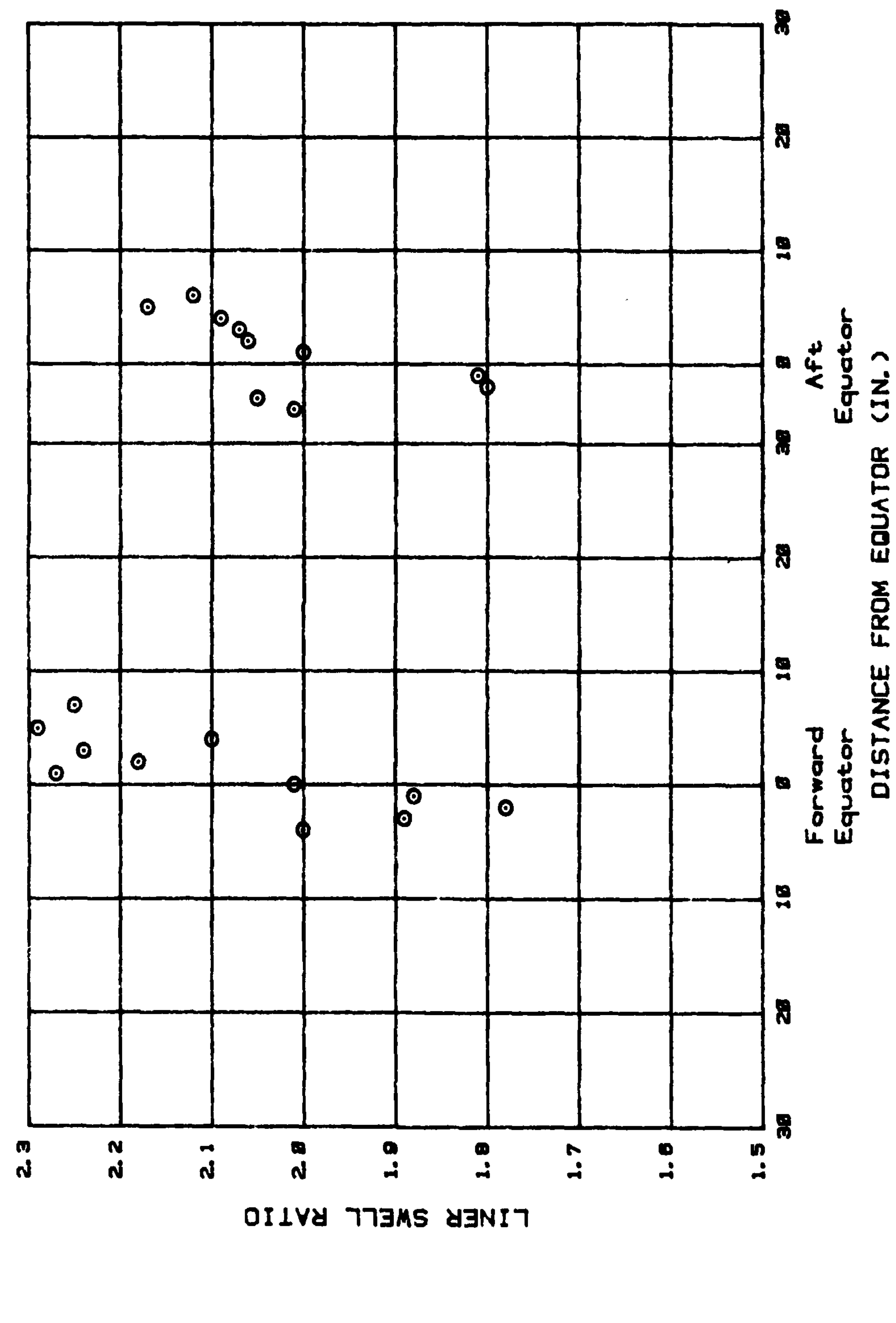


Figure 47. Liner Swell Ratio at Various Motor Locations in Motor TC 30072

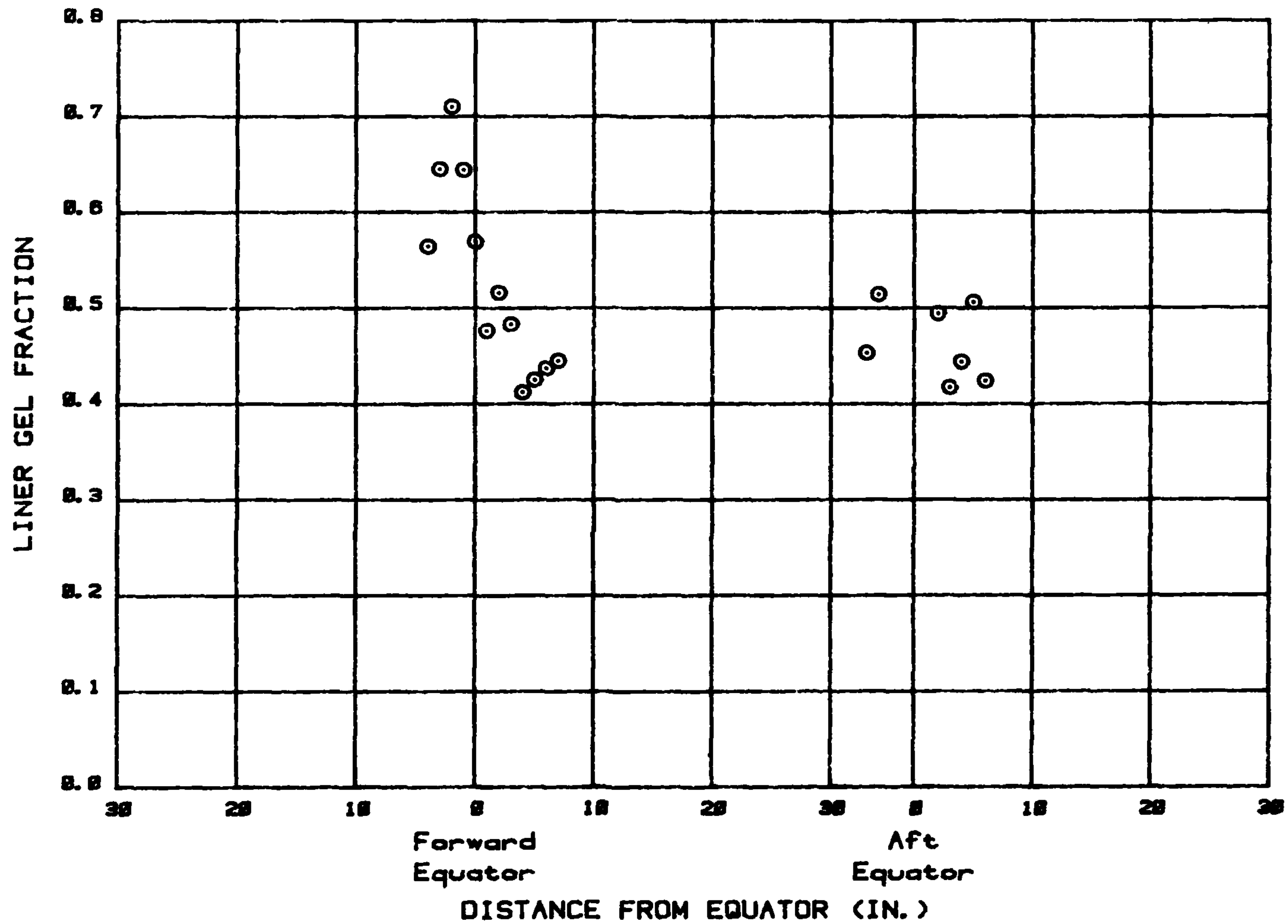


Figure 48. Liner Gel Fraction at Various Motor Locations in Motor TC 30072

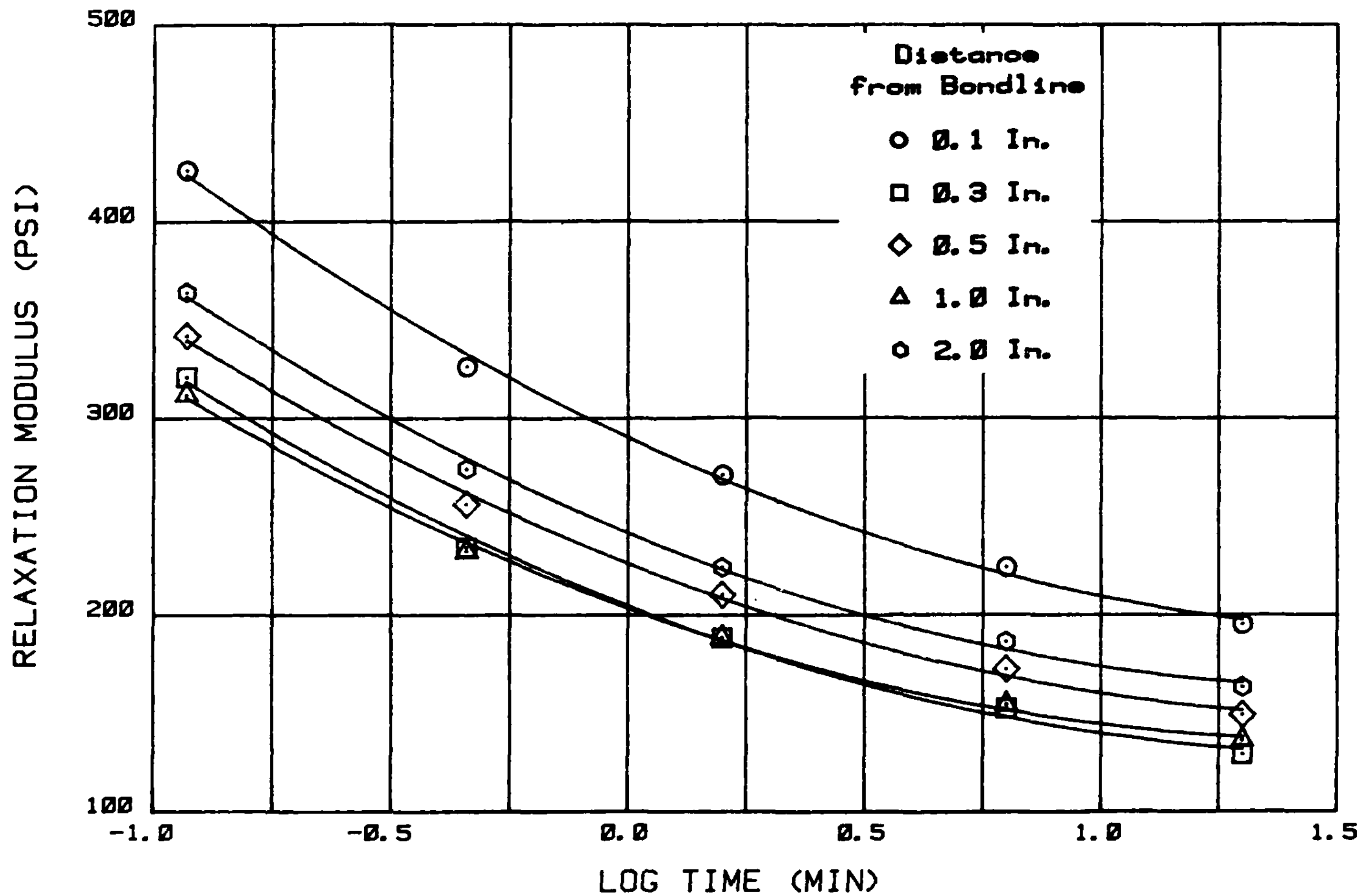


Figure 49. Motor TC 30072 Relaxation Modulus Gradient of ANB-3066 Propellant at the Forward Flap, Segment 1A1

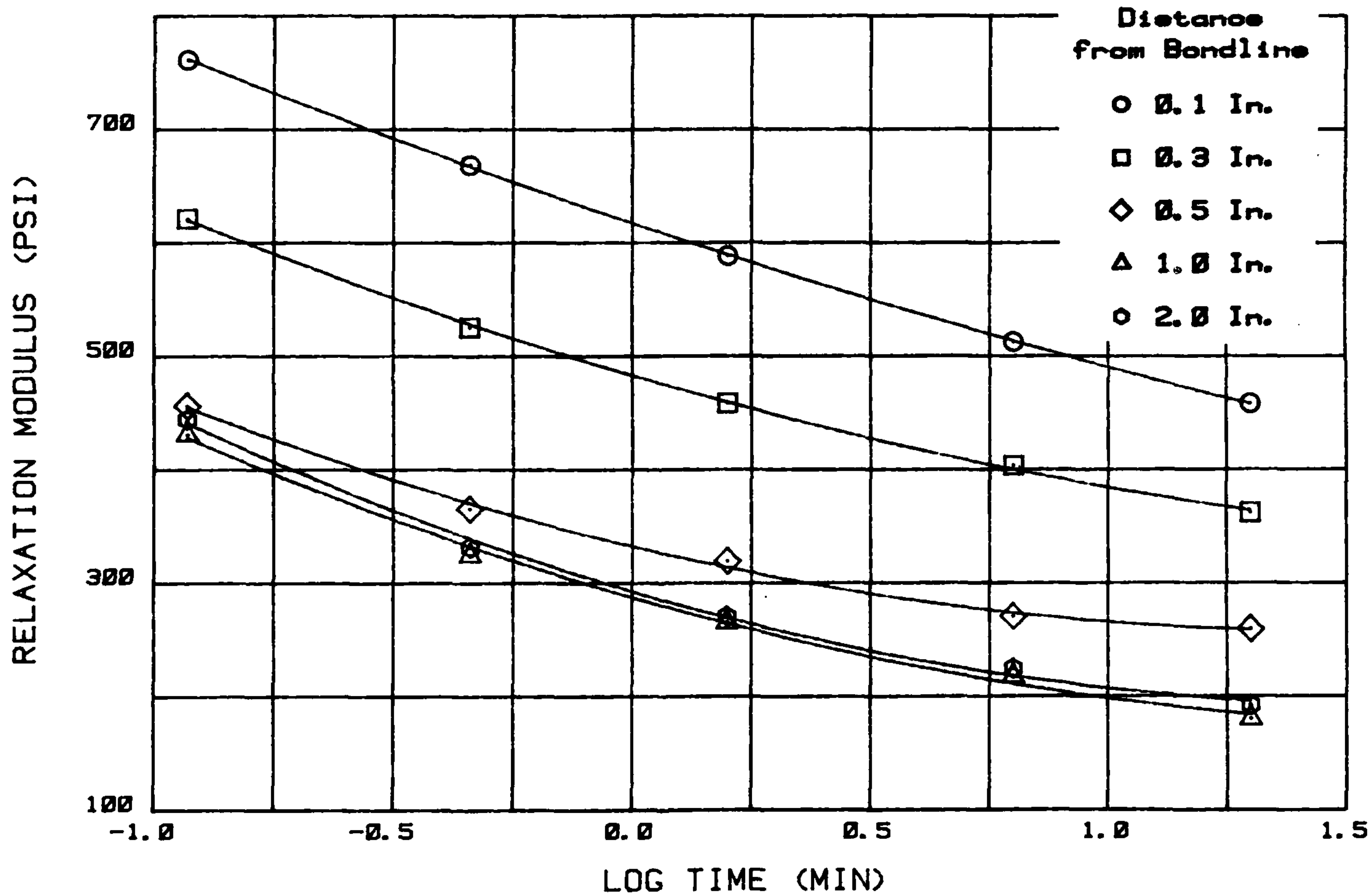


Figure 50. Motor TC 30072 Relaxation Modulus Gradient of ANB-3066 Propellant in the Barrel Area, Under the Grounding Straps

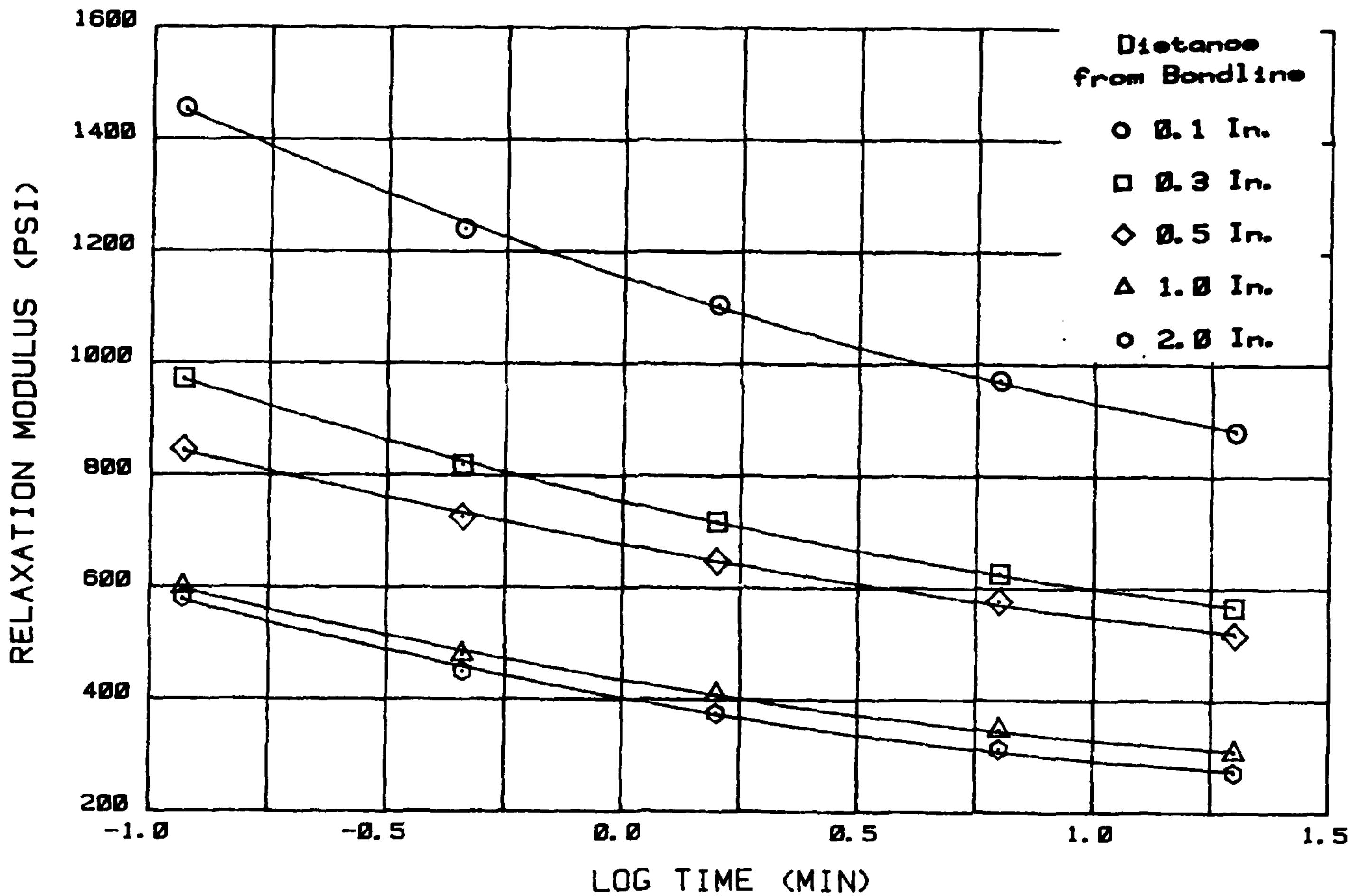


Figure 51. Motor TC 30072 Relaxation Modulus Gradient of ANB-3066 Propellant in the Barrel, Under Grounding Straps

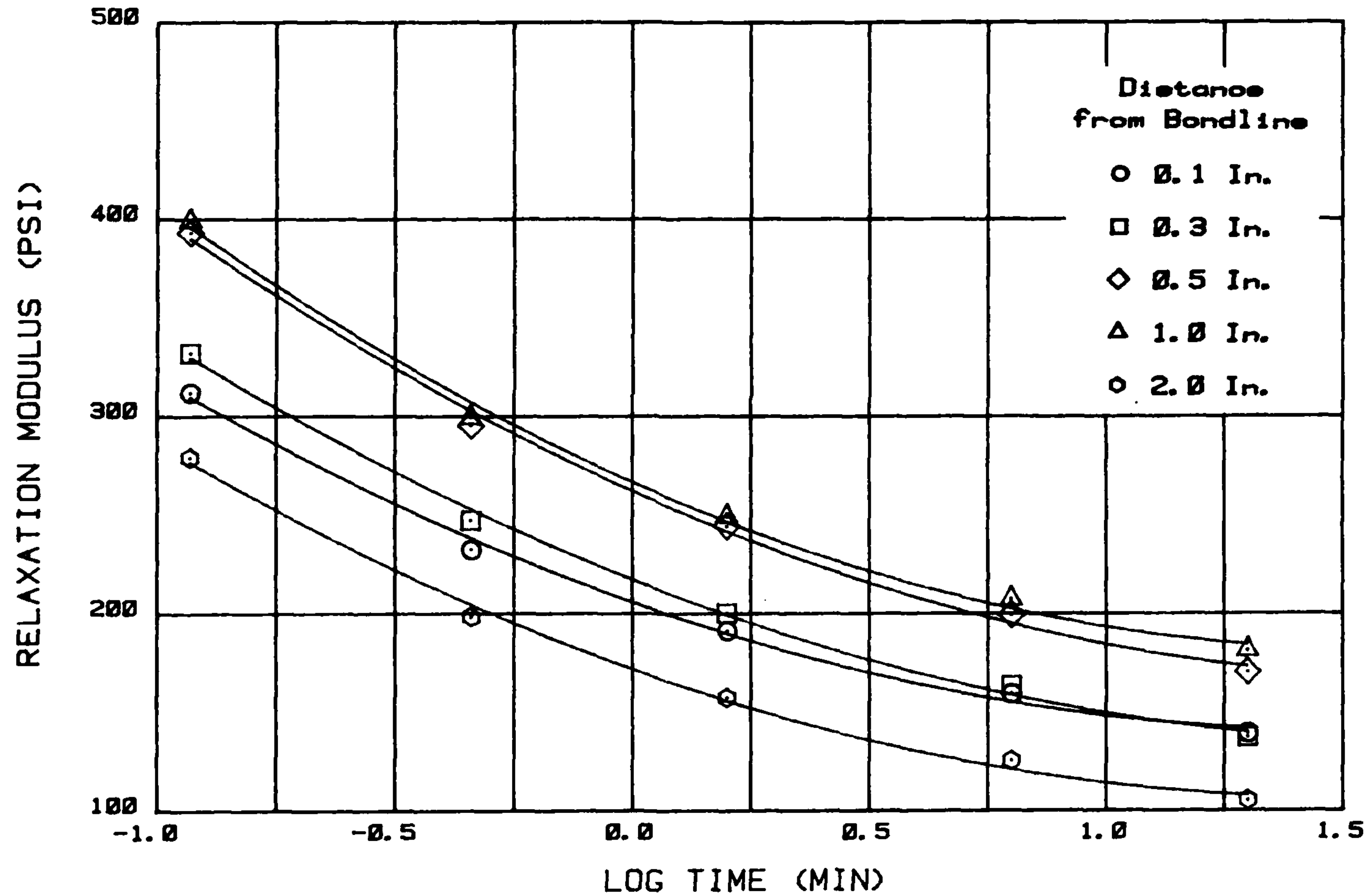


Figure 52. Motor TC 30072 Relaxation Modulus Gradient of ANB-3066 Propellant at the Forward Nipple Area

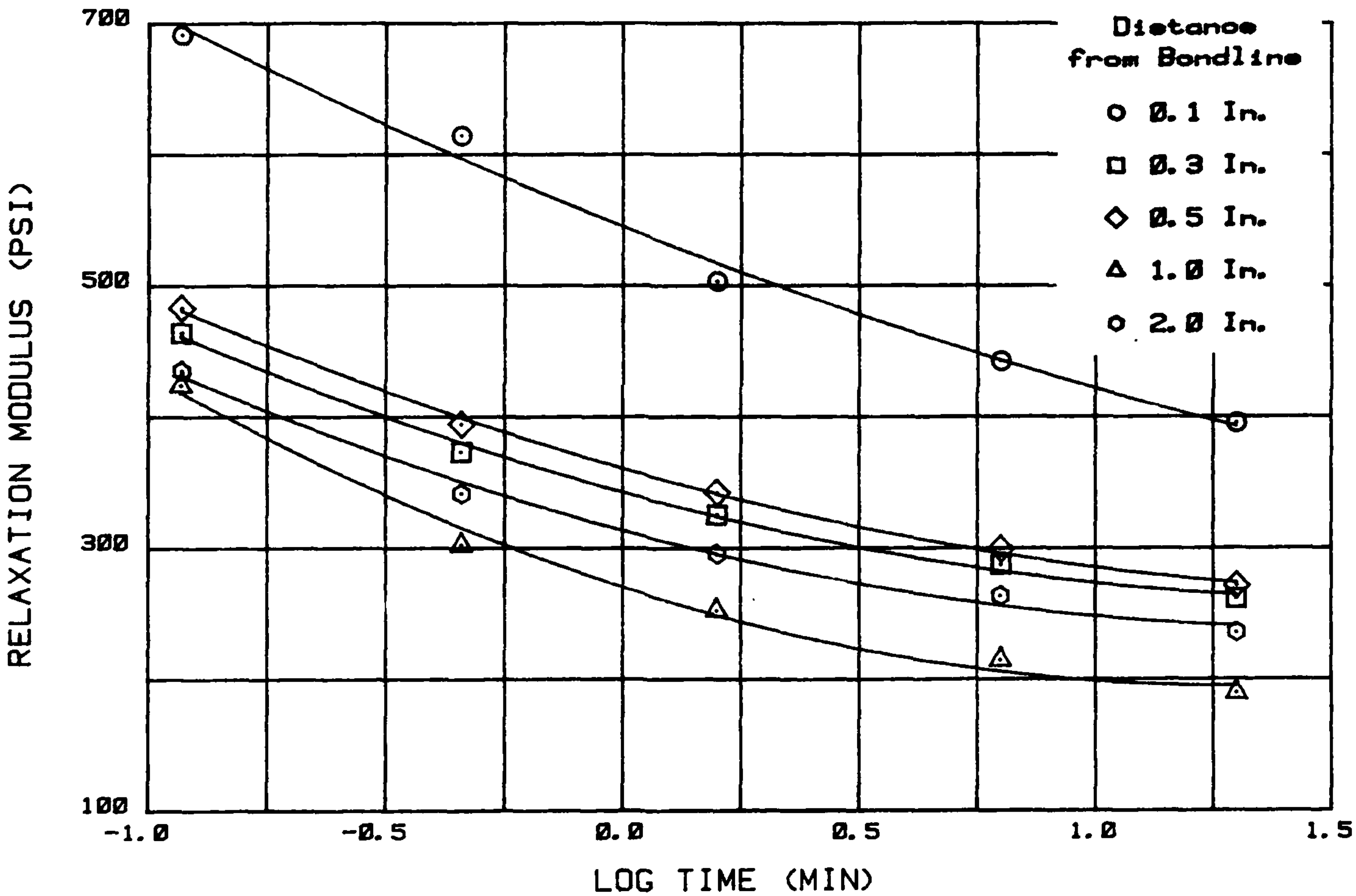


Figure 53. Motor TC 30072 Relaxation Modulus Gradient of ANB-3066 Propellant at the Forward Equator, Area A

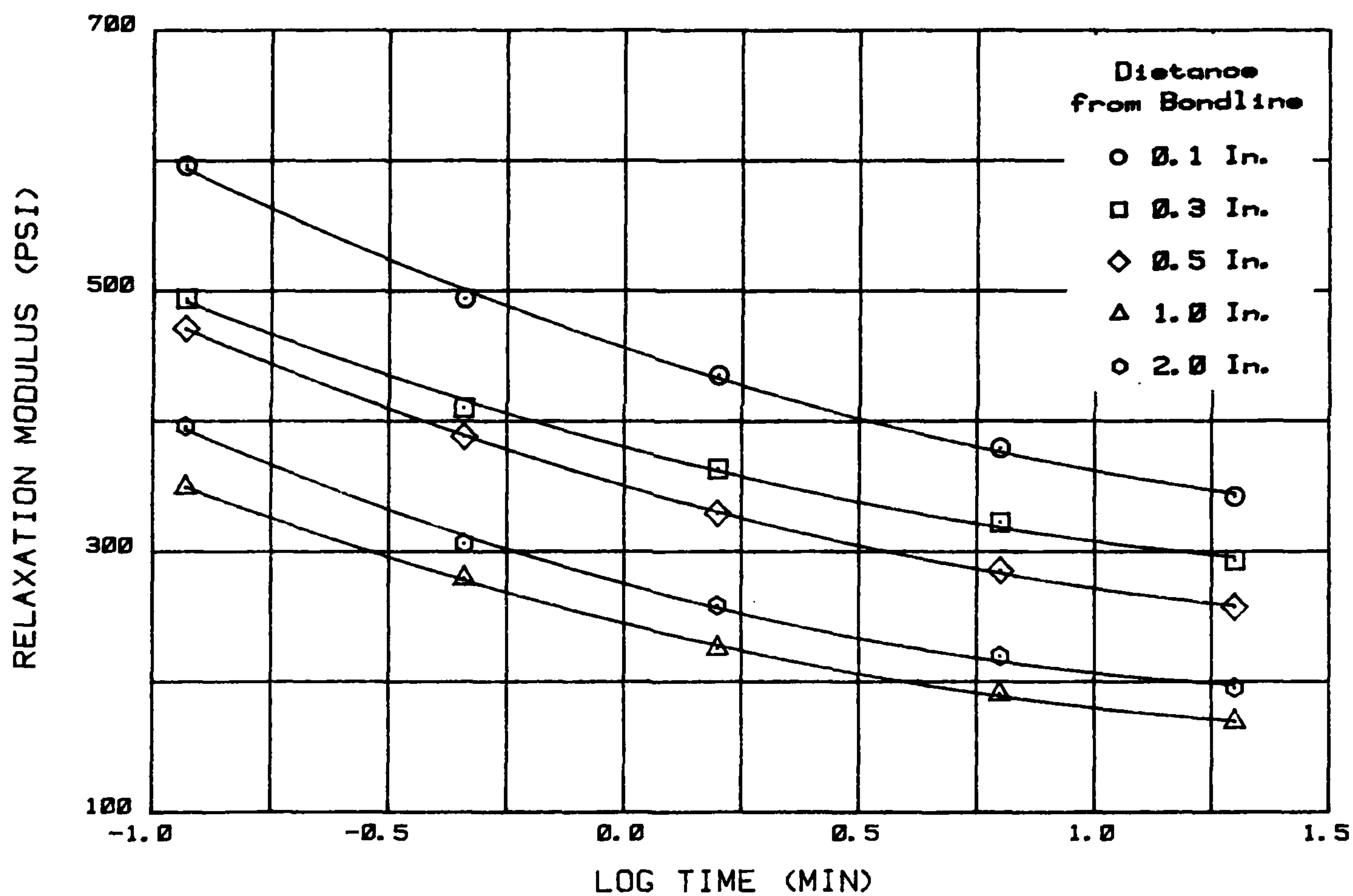


Figure 54. Motor TC 30072 Relaxation Modulus Gradient of ANB-3066 Propellant at the Forward Equator, Area B

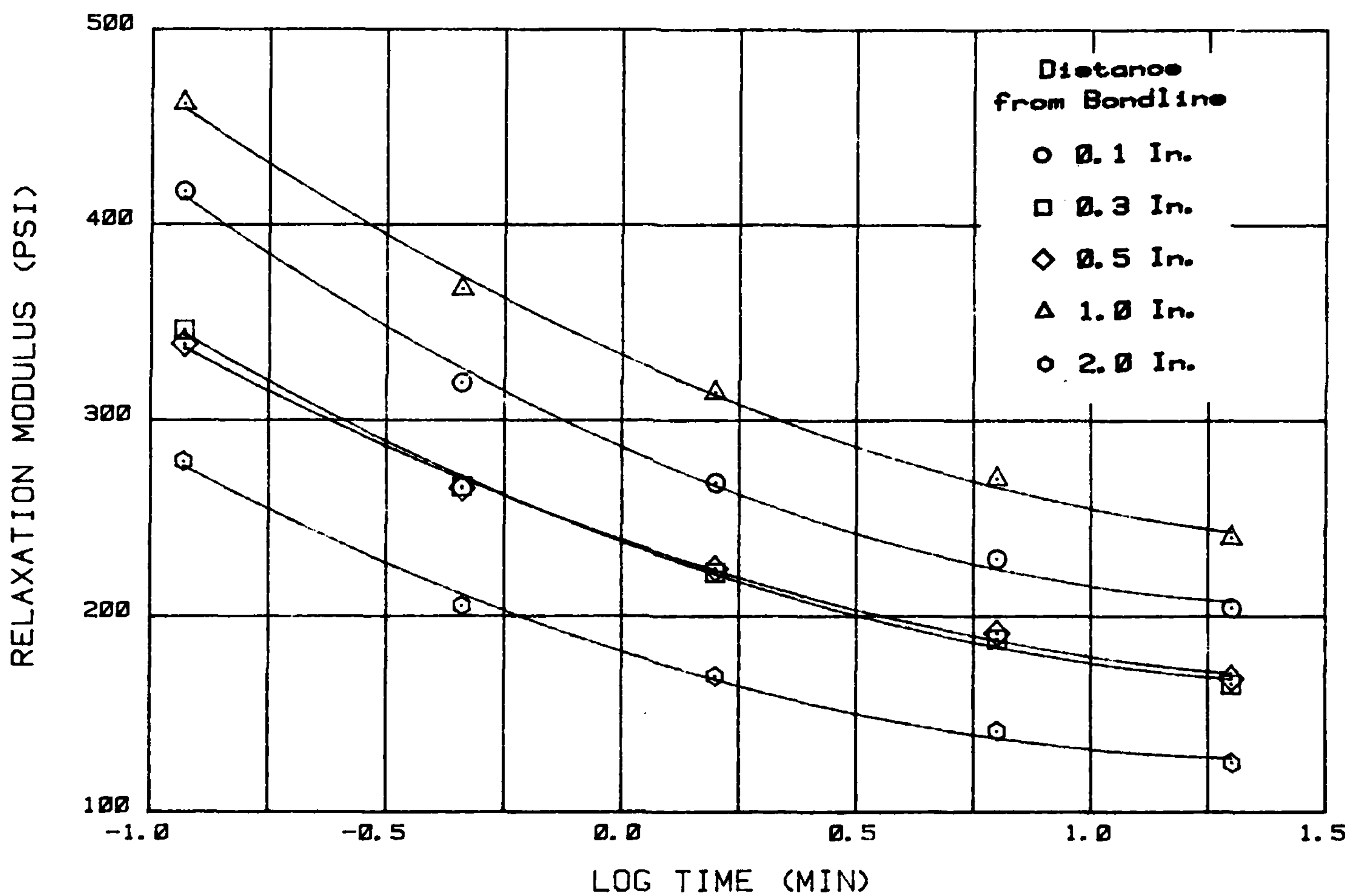


Figure 55. Motor TC 30072 Relaxation Modulus Gradient of ANB-3066 Propelalnt at the Forward Equator, Area C

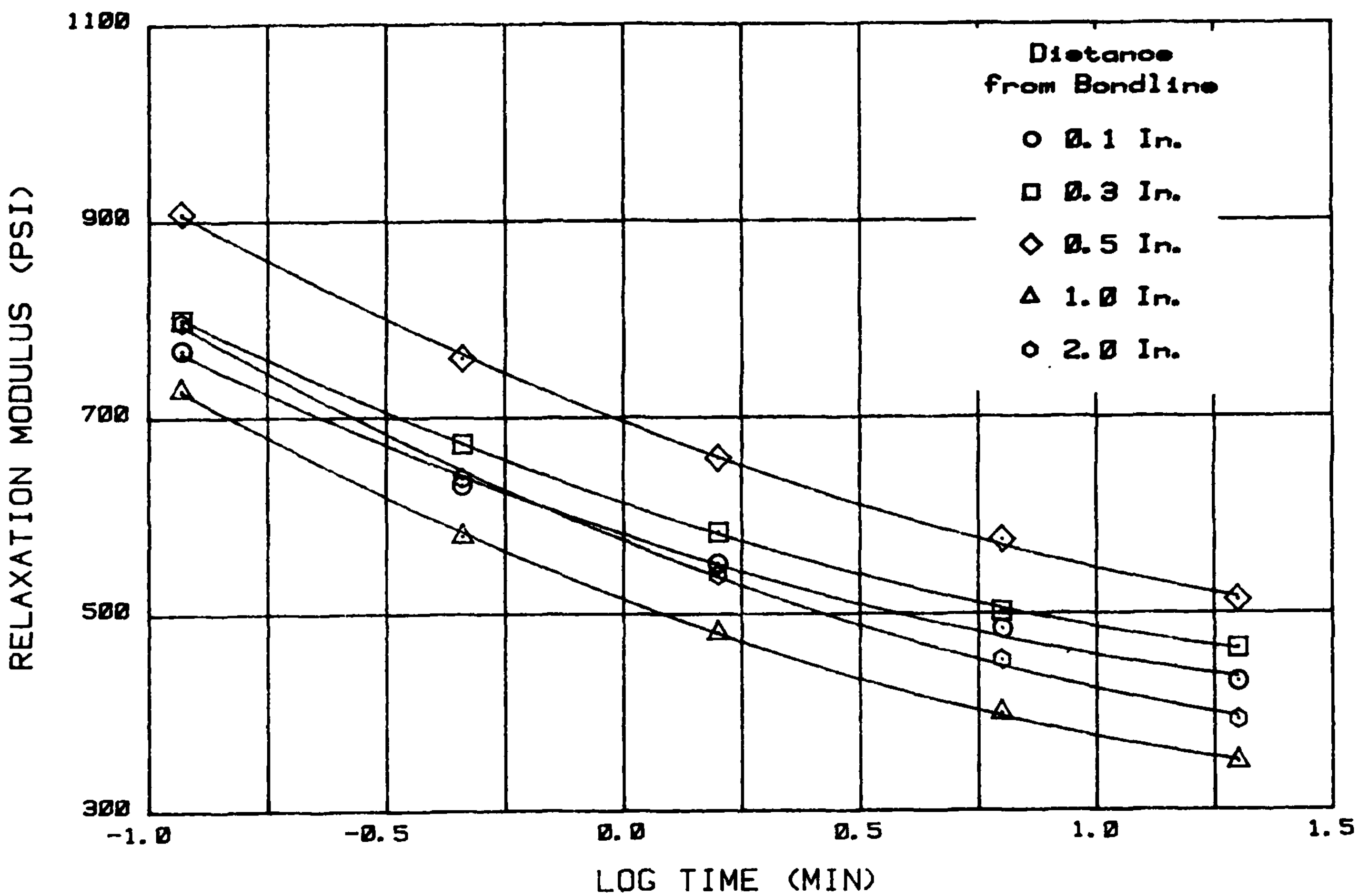


Figure 56. Motor TC 30072 Relaxation Modulus Gradient of ANB-3066 Propellant at the Aft Equator, Area A

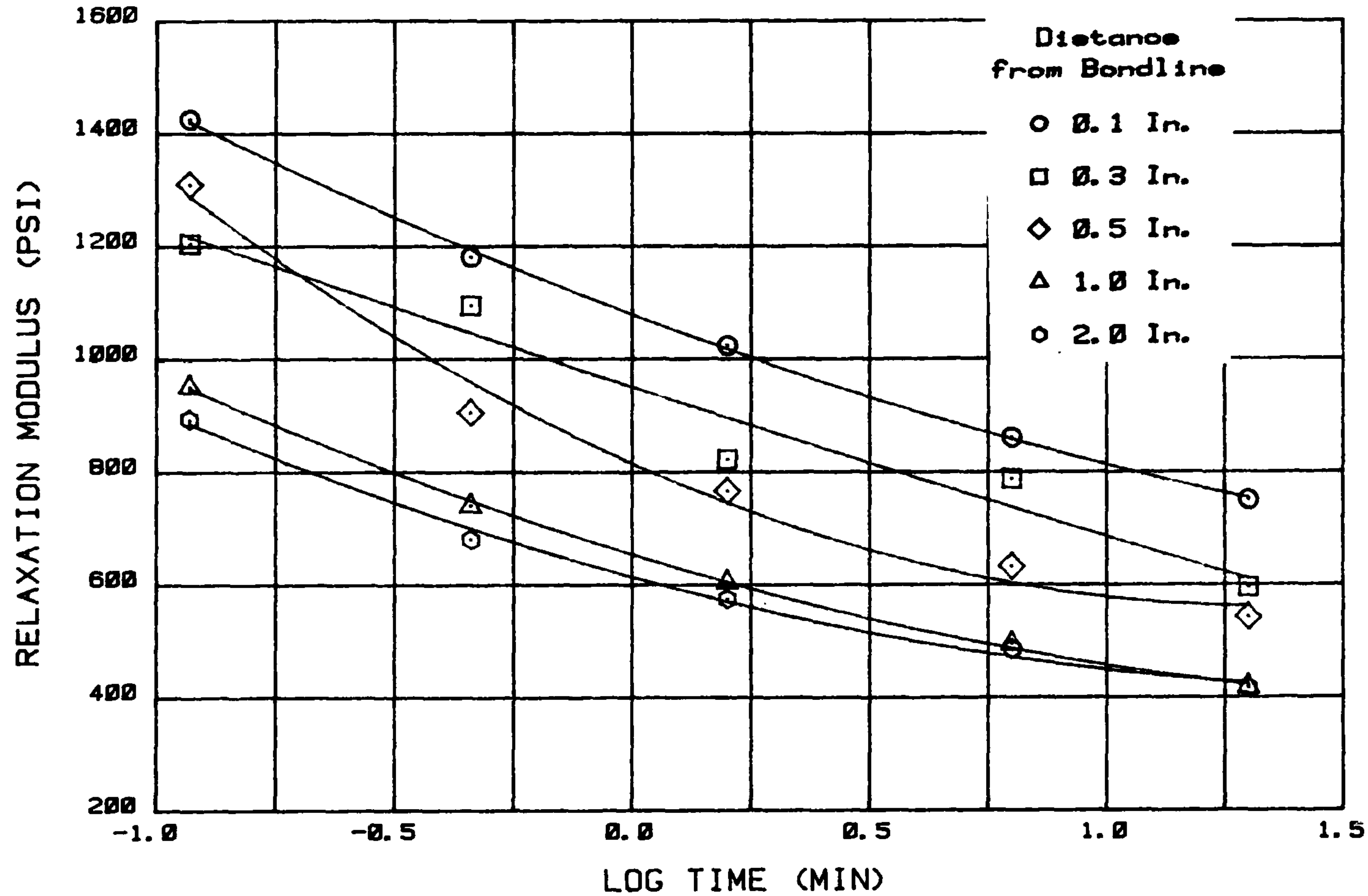


Figure 57. Motor TC 30072 Relaxation Modulus Gradient of ANB-3066 Propellant at the Aft Equator, Area B

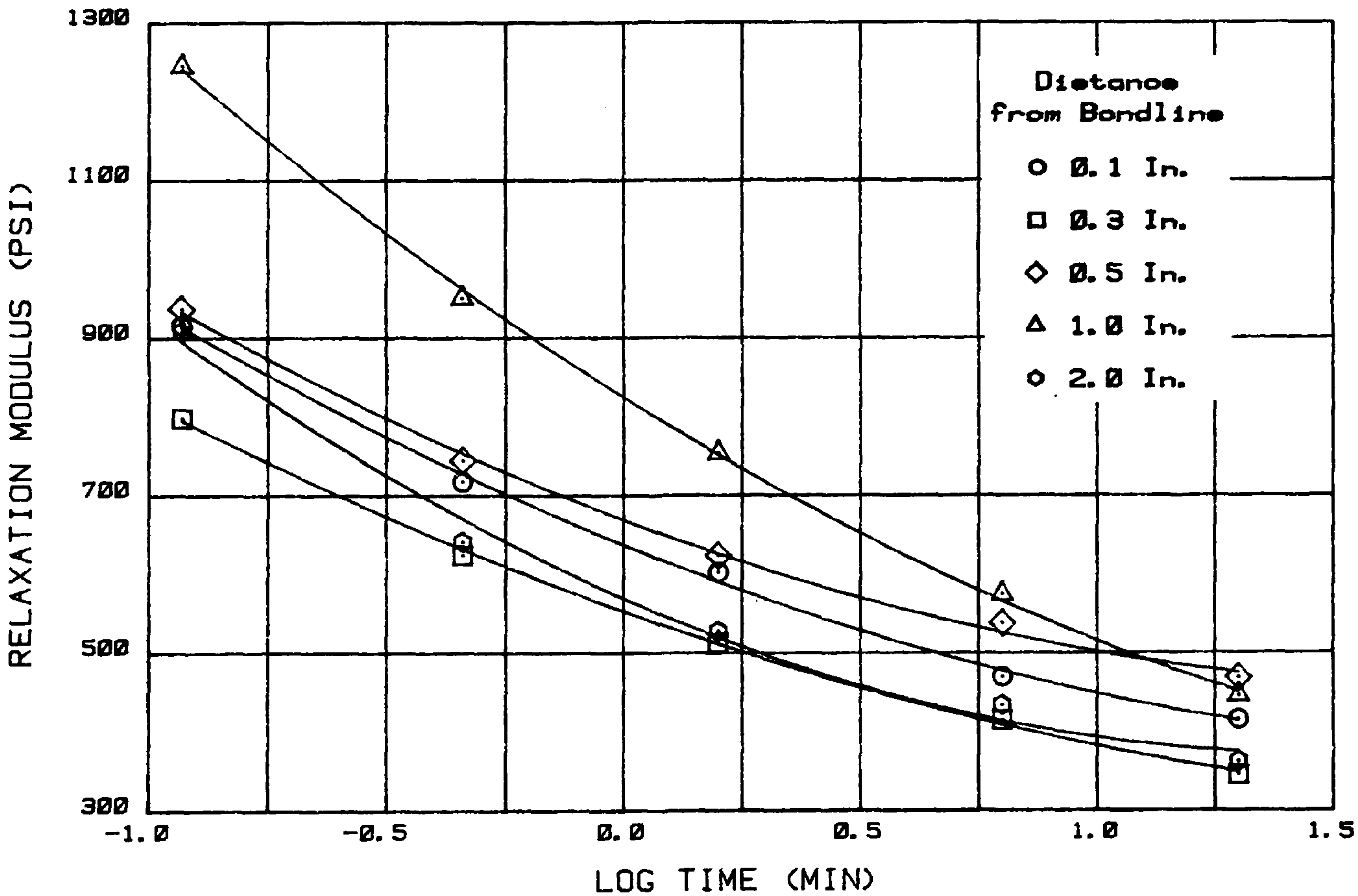


Figure 58. Motor TC 30072 Relaxation Gradient of ANB-3066 Propellant at the Aft Equator, Area C

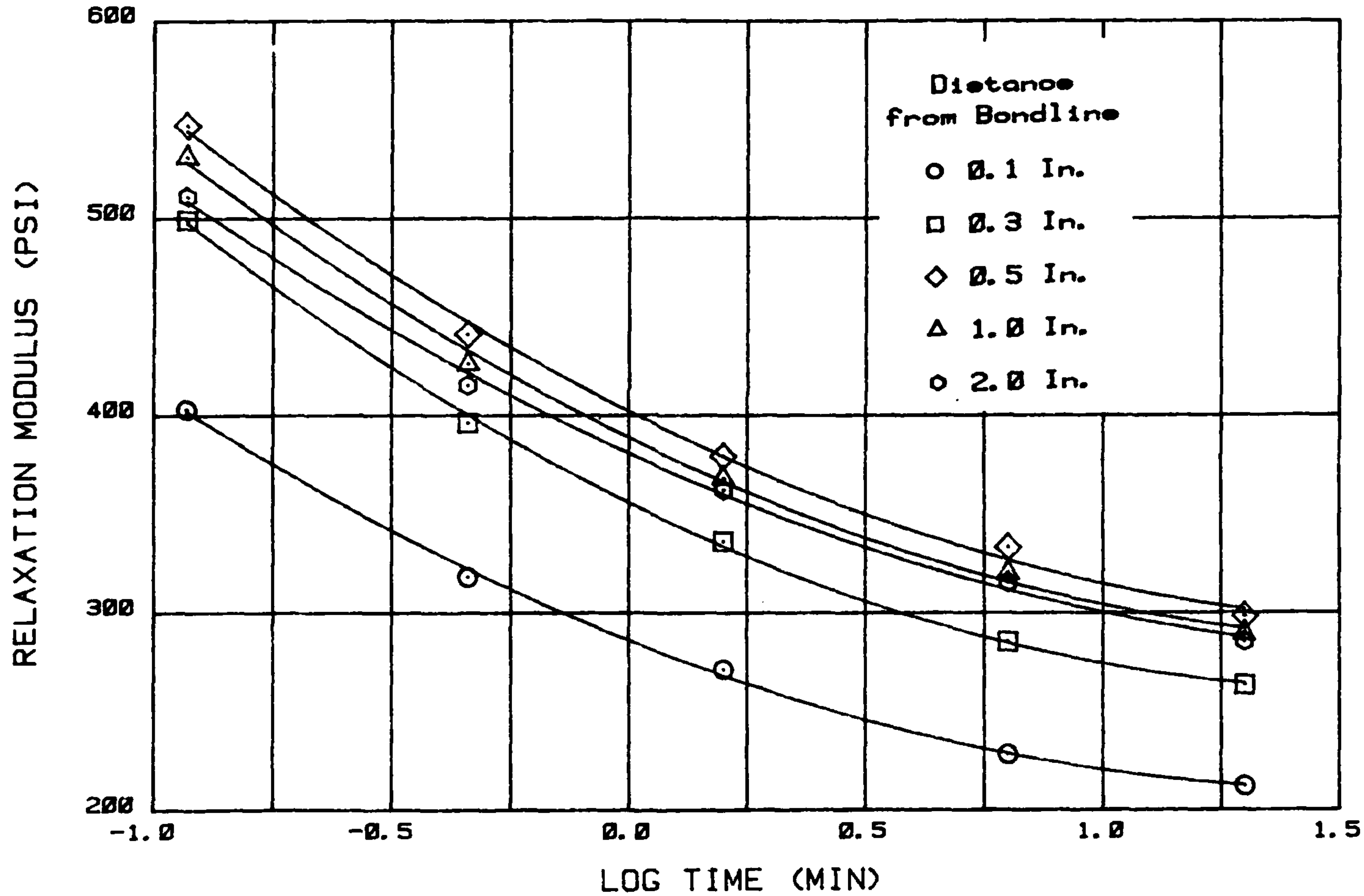


Figure 59. Motor TC 30072 Relaxation Modulus Gradient of ANB-3066 Propellant at the Aft Flap, Area D

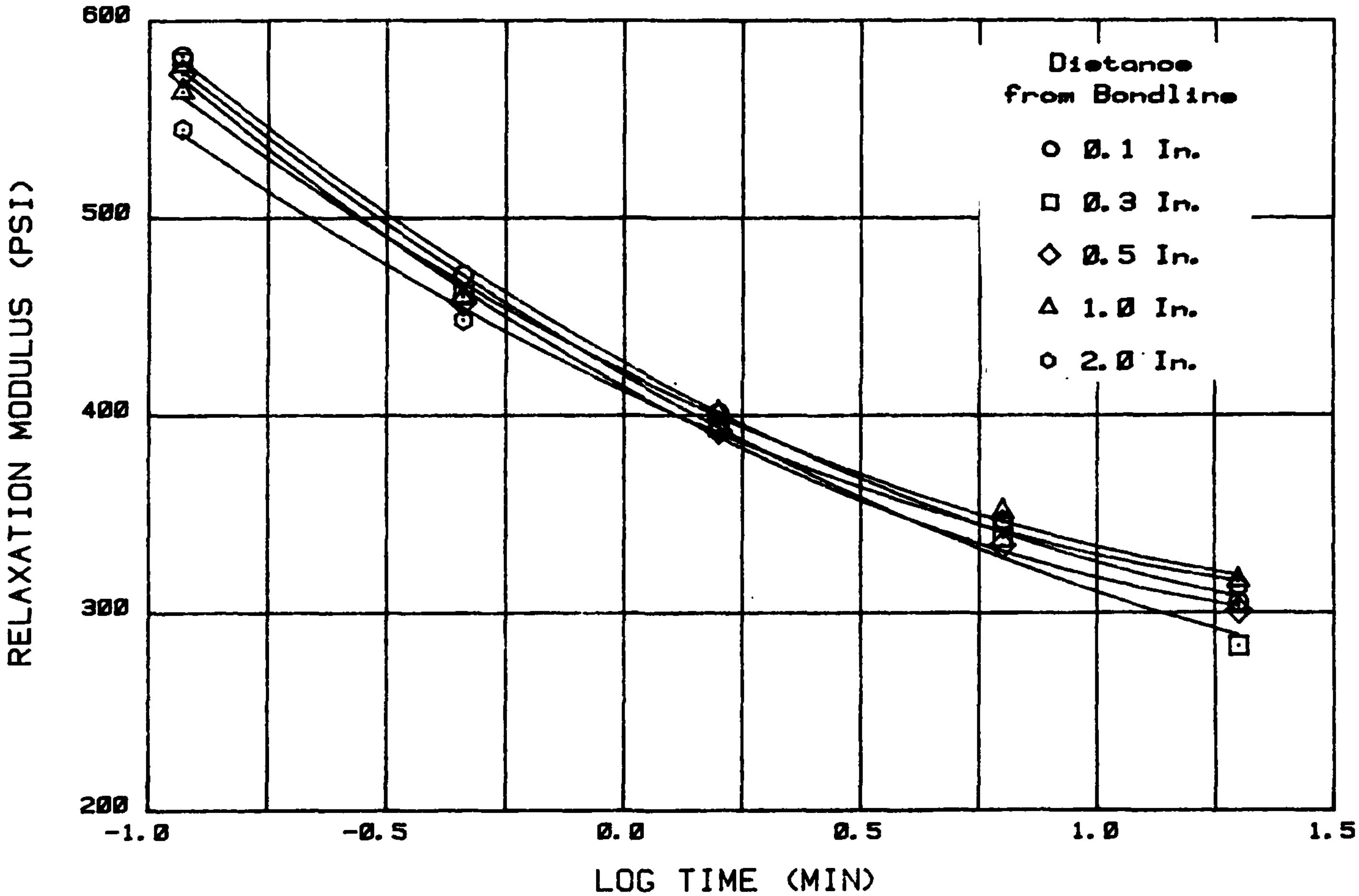


Figure 60. Motor TC 30072 Relaxation Modulus Gradient of ANB-3066 Propellant at the Aft Flap, Area E

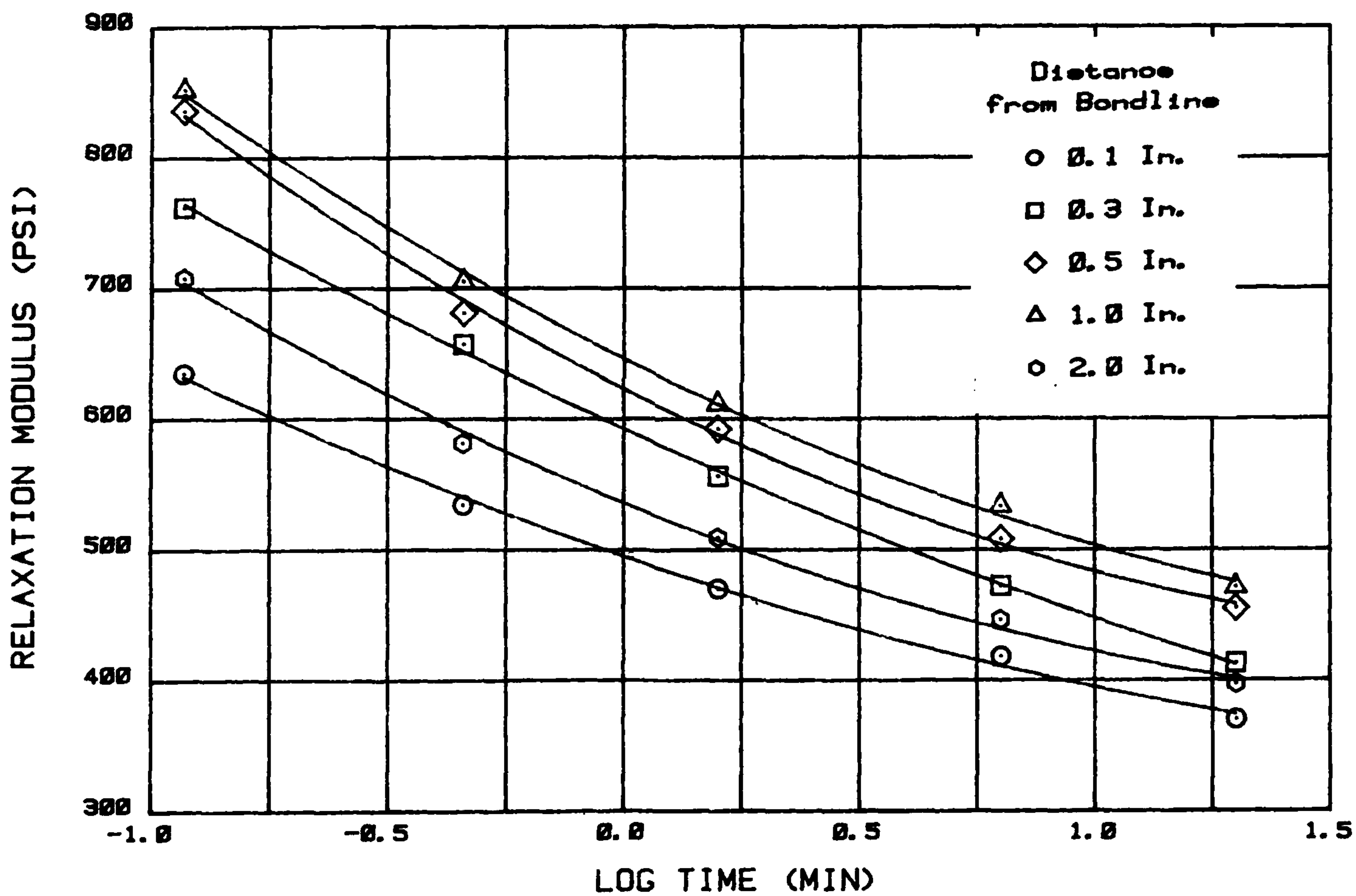


Figure 61. Motor TC 30072 Relaxation Modulus Gradient of ANB-3066 Propellant at the Aft Flap, Area F

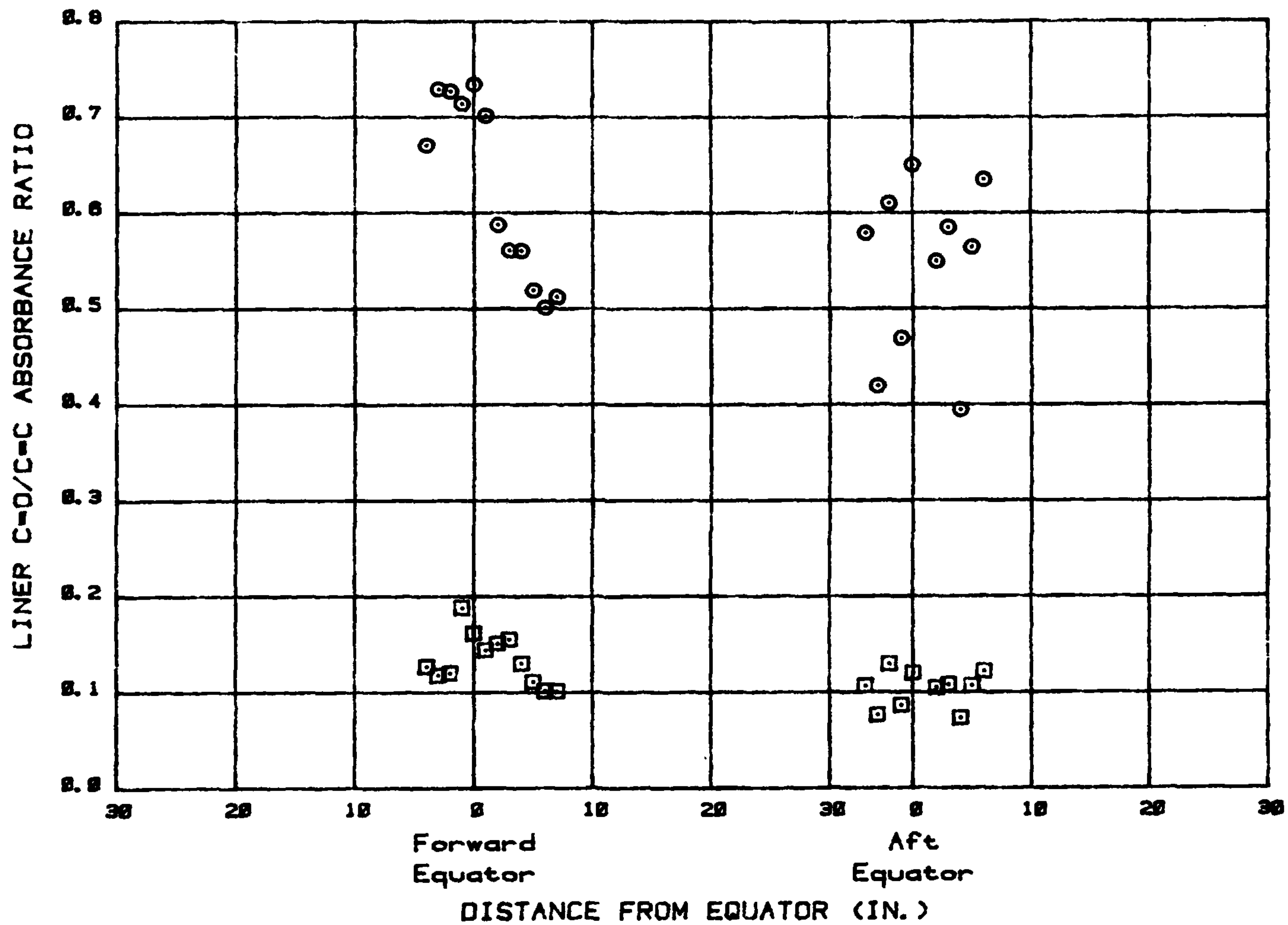


Figure 62. Motor TC 30072 Liner C=O/C=C (Vinyl and Stretching) Absorbance Ratio at Various Motor Locations

TABLE 1

SEGMENT USAGE BY TEST DATE

Test Date	Identification of Motor Segments*				
	Barrel, Between Aluminum Straps	Barrel, Under Aluminum Straps	Forward Equator	Aft Flap Near Bore	Forward Flap
1978	3D, 4D	3C, 4C	2C1	6B	1B1
1979	3H**	3G	2H1	None	1E5
1980	3L	3K	2L1	None	1B8
1981	None	None	2D1	6E	1B3
1982	4J	4I	2J1	None	1E6
1983	None	None	2B1	None	1B4
1984	4F	4E	2F1	6C	1E3
1985	None	None	2L2	None	1B6
1986	4L	4K	2D2	None	1E8
1987	None	None	2J2	6F	1B2
1988	3B	3A	2B2	None	1E4
1989	None	None	2F2	None	1B5
1990	4H	4G	2H2	6D	1E1
Spare	3F**, 3J, 4B	3E, 3I, 4A	2A1, 2E1, 2G1, 2I1, 2K1	6A	1B7, 1E2, 1E7

*Section/Segment/(Subsegment).
**Half of 3F segments from Motors TC 30005 & TC 30019 were used in 1979 testing.

TABLE 2

MATRIX FOR MINUTEMAN STAGE III BONDLINE AGING PROGRAM

Sample Area	Materials	Material Property	Test Conditions[1]	Specimen Type	Number/ Motor
Barrel, Between Aluminum Straps	ANB-3066/ SD-851-2/V-45	Bond Shear	Constant Strain Rate	Poker Chip	6
		Bond Tensile[2]	Constant Strain Rate	Round Flap	6
		Bond Tensile	0.5 in/min	Mini-DPT	3
	ANB-3066	E_R Profile[3]	2.0% Strain	Mini-Tensile	12
		Hardness[4]	15 sec.	(Shore A)	20
	SD-851-2	E_R	10 sec.	Penetrometer	3
		Swell Ratio	--	--	3
		Gel Fraction	--	--	3
		Moisture	--	--	3
Barrel, Under Aluminum Straps	ANB-3066/ SD-851-2/V-45	Bond Shear	Constant Strain Rate	Poker Chip	6
	SD-851-2	E_R	10 sec.	Penetrometer	3
		Swell Ratio	--	--	3
		Gel Fraction	--	--	3
		Moisture	--	--	3

(1) All tests at 77°F, 0 psi.
(2) See text, Sections 4.2.1.1 and 4.2.1.2.
(3) 0.1, 0.5, 1.0, and 2.0 in. from bondline.
(4) 0.1 in. intervals from bondline to 2 inches.

TABLE 2 (CONT)

MATRIX FOR MINUTEMAN STAGE III BONDLINE AGING PROGRAM

Sample Area	Materials	Material Property	Test Conditions (1)	Specimen Type	Number/ Motor
Forward Equator	ANB-3066/ SD-851-2/V-45	Bond Tensile Profile (5)	0.5 in./min.	Mini-DPT	21
	ANB-3066	E_R Gradient (6)	2.0% Strain	Mini-Tensile	12
		Hardness (4)	15 Sec.	(Shore A)	20
	SD-851-2	E_R (5)	10 sec.	Penetrometer	21
		Swell Ratio (5)	--	--	21
		Gel Fraction (5)	--	--	21
		Moisture (5)	--	--	21
Aft Flap Near bore area (7)	ANB-3066/ SD-851-2/V-45	Bond Tensile (8)	0.5 in./min.	Mini-DPT	3
	ANB-3066	E_R Gradient (9)	2.0% Strain	Mini-Tensile	9
		Hardness	15 Sec.	(Shore A)	3
	SD-851-2	Swell Ratio (8)	--	--	9
		Gel Fraction (8)	--	--	9
	V-45	Moisture	--	--	9
		Hardness	15 Sec.	(Shore A)	3
		E_R	2.0% Strain	0.05 x 0.5 x 4	3
		DOP Content	--	--	3
		Swell Ratio	--	--	9
Forward Flap	Testing will be identical to aft flap.				

(5) 2 in. forward to 10 in. aft of forward equator in 2 in. increments, 7 locations (between aluminum straps in barrel).
(6) 0.1, 0.5, 1.0, and 2.0 in. from bondline at equator only.
(7) Sample at 3 year intervals.
(8) Taken from 3 separate locations along the sample.
(9) Test at 0.1, 0.3, and 0.5 in. from bond interface.

TABLE 3

MOTOR TC 30005 MATERIAL PROPERTIES DATA
FORWARD EQUATOR AREA, SEGMENT 2L2
7-YEAR (1985) RESULTS

Distance Aft of Forward Equator (in.)	Maximum Stress (psi)	Failure Mode (%) APL	Failure Mode (%) CL	Failure Mode (%) CLI	Liner Moisture (%)	Distance Aft of Forward Equator (in.)	Liner Swell Ratio	Liner Gel Fraction
-2	22	5	95	-	0.26	-1	2.20	0.395
	24	5	95	-			2.13	0.431
	33	5	95	-			2.20	0.440
	26						2.18	0.422
0	42	70	30	-	0.56	1	1.84	0.626
	43	75	25	-			1.85	0.609
	42						1.83	0.610
							1.84	0.615
2	74	75	25	-	0.60	3	1.94	0.565
	82	80	20	-			2.00	0.593
	72	80	20	-			2.00	0.566
	76						1.98	0.575
4	61	80	20	-	1.02	5	2.16	0.508
	48	80	20	-			2.13	0.502
	44	80	20	-			2.09	0.490
	51						2.13	0.500
6	48	40	50	10	0.64	7	1.88	0.585
	34	40	50	10			1.88	0.577
	59	60	40	-			1.93	0.511
	47						1.90	0.558
8	60	80	20	-	0.35	9	2.06	0.513
	58	80	20	-			2.00	0.518
	47	80	20	-			2.00	0.534
	55						2.02	0.522
10	34	60	40	-	0.49	11	2.07	0.463
	53	60	40	-			2.00	0.480
	38	60	40	-			2.07	0.432
	43						2.05	0.459

TABLE 4

MOTOR TC 30019 MATERIAL PROPERTIES DATA
FORWARD EQUATOR AREA, SEGMENT 2L2
7-YEAR (1985) RESULTS

Distance Aft of Forward Equator (in.)	Maximum Stress (psi)	Failure Mode (%) APL	CL	CLI	Liner Moisture (%)	Distance Aft of Forward Equator (in.)	Liner Swell Ratio	Liner Gel Fraction
-2	30	-	100	-	0.16	-1	2.11	0.449
	24	-	100	-			2.17	0.426
	27		95				2.11	0.430
	27						2.13	0.435
0	65	75	25	-	0.52	1	1.83	0.577
	66	90	10	-			1.89	0.568
	66	80	20	-			1.78	0.561
	66						1.83	0.569
2	94	80	20	-	0.28	3	1.86	0.573
	90	80	20	-			1.83	0.536
	97	80	20	-			1.83	0.554
	94						1.84	0.553
4	82	95	5	-	0.31	5	2.00	0.524
	83	95	5	-			1.88	0.510
	85	90	10	-			1.88	0.483
	83						1.92	0.505
6	63	95	5	-	0.34	7	1.92	0.457
	80	95	5	-			1.92	0.457
	71	95	5	-			1.92	0.444
	71						1.92	0.453
8	52	80	20	-	0.26	9	1.87	0.462
	45	70	30	-			2.00	0.443
	64	80	20	-			2.00	0.494
	54						1.96	0.466
10	57	80	20	-	0.33	11	2.24	0.441
	77	80	20	-			2.24	0.423
	50	80	20	-			2.19	-
	61						2.22	0.432

TABLE 5

MOTOR TC 30033 MATERIAL PROPERTIES DATA
FORWARD EQUATOR AREA, SEGMENT 2L2
7-YEAR (1985) RESULTS

Distance Aft of Forward Equator (in.)	Maximum Stress (psi)	Failure Mode (%) APL	CL	CLI	Liner Moisture (%)	Distance Aft of Forward Equator (in.)	Liner Swell Ratio	Liner Gel Fraction
-2	36	10	90	-	-	-1	1.91	0.416
	32	-	100	-			1.95	0.374
	19	-	100	-			1.93	0.339
	29						1.93	0.376
0	41	60	40	-	-	1	1.78	0.582
	47	90	10	-			1.65	0.615
	47	70	30	-			1.70	0.614
	45						1.71	0.605
2	77	95	5	-	-	3	1.93	0.525
	77	95	5	-			2.00	0.513
	69	95	5	-			1.93	0.517
	74						1.95	0.518
4	42	95	5	-	-	5	1.93	0.524
	40	80	20	-			1.93	0.549
	59	80	20	-			1.93	0.527
	47						1.93	
6	33	90	10	-	-	7	1.93	0.535
	39	90	10	-			1.93	0.540
	51	95	5	-			1.97	0.524
	41						1.94	0.533
8	59	90	10	-	-	9	2.00	0.485
	41	95	5	-			2.00	0.511
	35	95	5	-			2.00	0.517
	45						2.00	0.504
10	37	90	10	-	-	11	2.06	0.455
	45	90	10	-			2.13	0.468
	-	-	-	-			2.06	0.381
	41						2.08	0.435

TABLE 6

MOTOR TC 30005 STRESS RELAXATION GRADIENT
ANB-3066 PROPELLANT, FORWARD EQUATOR AREA, AMBIENT
SEGMENT 2L2 7-YEAR (1985) RESULTS

Distance From Bondline (in.)	Time From Cutting (hrs)	Strain (%)	Relaxation Modulus (psi) Log Time (min) -0.93	-0.34	0.20	0.80	1.30
0.1	2.3	2.00	753	607	518	441	398
	3.0	2.00	808	666	579	502	455
	3.1	2.00	1160	978	857	746	672
		2.00	907	750	651	563	508
0.5	2.9	1.99	867	714	615	528	477
	3.1	2.01	801	662	571	496	446
	-	2.00	-	-	-	-	-
			834	688	593	512	461
1.0	3.1	2.01	742	663	507	429	387
	3.7	2.00	636	519	453	398	357
	3.1	2.00	722	584	496	423	378
		2.00	700	589	485	417	374
2.0	2.4	2.01	716	577	488	419	377
	2.9	1.99	795	644	551	470	417
	3.6	1.99	856	698	596	512	459
		2.00	789	640	545	467	417

TABLE 7

MOTOR TC 30019 STRESS RELAXATION GRADIENT
ANB-3066 PROPELLANT, FORWARD EQUATOR AREA, AMBIENT
SEGMENT 2L2 7-YEAR (1985) RESULTS

Distance From Bondline (in.)	Time From Cutting (hrs)	Strain (%)	Relaxation Modulus (psi) Log Time (min) -0.93	-0.34	0.20	0.80	1.30
0.1	2.01	2.01	1000	884	771	667	606
	-	2.01	1250	1050	924	803	720
	-	2.00	1250	1060	930	805	723
		2.01	1167	998	875	758	683
0.5	-	2.00	1000	851	727	633	567
	-	2.00	808	663	576	498	446
	-	2.00	635	511	441	378	338
		2.00	814	675	581	503	450
1.0	-	1.99	699	557	472	401	357
		2.00	720	583	504	435	387
		2.00	721	585	501	433	387
		2.00	713	575	492	423	377
2.0	-	1.98	729	594	512	442	394
	-	2.01	879	728	633	552	494
	-	2.00	794	662	578	503	451
		2.00	801	661	574	499	446

TABLE 8

MOTOR TC 30033 STRESS RELAXATION GRADIENT
ANB-3066 PROPELLANT, FORWARD EQUATOR AREA, AMBIENT
SEGMENT 2L2 7-YEAR (1985) RESULTS

Distance From Bondline (in.)	Time From Cutting (hrs)	Strain (%)	Relaxation Modulus (psi) Log Time (min)				
			-0.93	-0.34	0.20	0.80	1.30
0.1	-	2.00	611	497	430	373	332
		2.00	800	668	583	511	461
		2.00	841	705	623	543	488
		2.00	751	623	545	475	427
0.5	-	1.99	936	782	616	533	476
		2.01	804	658	575	499	449
		2.00	621	492	438	370	335
		2.00	787	644	543	467	420
1.0	-	2.00	554	439	375	320	285
		2.01	663	503	426	363	327
		2.00	618	502	433	376	337
		2.00	612	481	411	353	316
2.0	-	1.98	635	516	444	382	342
		2.00	700	570	493	413	385
		2.01	772	635	552	481	418
		2.00	702	574	496	425	382

TABLE 9

PROPELLANT SHORE A HARDNESS, 15-SECOND READINGS
FORWARD FLAP AREA, SEGMENT 1B6, AREA A
7-YEAR (1985) RESULTS

Distance From Bondline (in.)	Motor		
	TC 30005	TC 30019	TC 30033
0.1	44±1.1[1]	44±1.0	50±1.53
0.2	50±1.0	47±0.0	55±1.1
0.3	51±0.6	48±0.6	57±0.6
0.4	52±0.6	46±0.0	60±1.1
0.5	51±1.0	48±0.0	60±1.0
0.6	53±0.6	48±1.5	62±0.6
0.7	60±0.0	50±2.1	63±1.0
0.8	61±0.6	51±1.1	64±0.6
0.9	60±0.6	51±1.1	63±0.6
1.0	61±0.6	53±1.5	64±1.0
1.1	61±0.6	57±1.5	64±1.0
1.2	60±1.0	58±2.0	64±1.0
1.3	59±1.0	59±0.6	64±0.6
1.4	58±0.6	61±1.7	66±0.6
1.5	55±0.6	63±1.0	65±0.0
1.6	52±0.6	63±0.6	63±0.6
1.7	50±0.0	64±0.6	62±1.0
1.8	49±1.5	63±1.0	61±1.1
1.9	46±0.6	64±0.6	60±0.0
2.0	45±1.0	64±0.6	61±0.6

[1]Standard Deviation for Triplicate Tests

AD-A164 288 MINUTEMAN STAGE III OPERATIONAL SURVEILLANCE PROGRAM SEVEN-YEAR TESTING B..(U) MORTON THIOKOL INC BRIGHAM CITY UT WASATCH DIV M R KNIGHT DEC 85 TWR-32333 2/2

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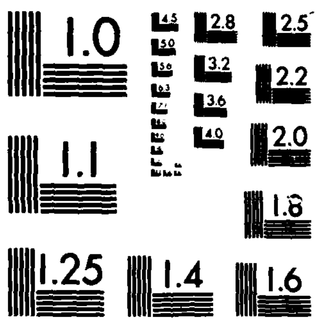

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TABLE 10

PROPELLANT SHORE A HARDNESS, 15-SECOND READINGS
FORWARD FLAP AREA, SEGMENT 1B6, AREA B
7-YEAR (1985) RESULTS

Distance From Bondline (in.)	Motor TC 30005	Motor TC 30019	Motor TC 30033
0.1	65±0.6[1]	57±0.6	59±1.1
0.2	65±1.1	59±1.0	61±0.6
0.3	65±0.6	59±1.1	62±1.0
0.4	64±1.0	57±1.0	61±0.6
0.5	65±2.1	57±0.6	59±1.0
0.6	64±1.0	55±0.6	58±0.6
0.7	65±0.6	54±0.6	56±0.6
0.8	62±0.6	56±2.1	55±0.0
0.9	60±0.6	55±0.6	56±0.6
1.0	60±0.6	55±0.6	55±0.0
1.1	59±0.6	56±1.0	56±0.6
1.2	58±0.0	56±0.6	55±0.6
1.3	57±0.0	57±1.1	54±0.6
1.4	58±0.6	56±1.0	52±0.0
1.5	58±0.6	58±0.6	53±0.6
1.6	56±0.0	60±1.0	50±0.6
1.7	54±0.6	60±0.6	49±0.0
1.8	54±0.6	59±0.6	47±0.6
1.9	54±0.0	60±0.6	47±1.0
2.0	52±0.0	60±1.0	46±0.6

[1]Standard Deviation for Triplicate Tests

TABLE 11

PROPELLANT SHORE A HARDNESS, 15-SECOND READINGS
FORWARD FLAP AREA, SEGMENT 1B6, AREA C
7-YEAR (1985) RESULTS

Distance From Bondline (in.)	Motor TC 30005	TC 30019	TC 30053
0.1	54±0.6[1]	60±0.6	57±2.3
0.2	53±0.0	64±0.6	59±0.6
0.3	50±0.0	67±0.6	58±1.0
0.4	45±0.6	67±0.6	58±0.6
0.5	43±0.6	65±0.6	58±0.6
0.6	41±0.6	61±0.6	59±0.6
0.7	42±0.0	60±0.6	61±0.6
0.8	41±0.6	58±0.6	62±0.0
0.9	42±0.6	58±0.6	64±0.6
1.0	43±0.0	56±1.0	67±0.0
1.1	43±0.6	55±0.6	67±0.6
1.2	43±0.6	54±0.6	66±0.6
1.3	40±0.6	55±0.6	65±0.6
1.4	39±0.6	56±0.6	65±0.0
1.5	38±0.6	55±0.6	63±0.6
1.5	40±0.6	56±0.6	60±0.6
1.7	39±0.6	57±0.6	57±0.0
1.8	41±0.6	56±0.6	55±0.6
1.9	42±0.6	57±0.6	54±1.0
2.0	43±0.6	57±0.6	52±0.6

Standard Deviation for Triplicate Tests

TABLE 12

V-45 RUBBER MATERIAL PROPERTIES DATA
FORWARD FLAP AREA, SEGMENT 1B6
7-YEAR (1985) RESULTS

Motor No.	V-45 Swell Ratio	V-45 Moisture (%) (Azocotropic)	V-45 Moisture (%) (Dupont)	V-45 DOP (%)	V-45 15-Second Shore A Hardness
TC 30005	1.56	-	1.46	1.21	61
	1.61	-	1.22	1.17	62
	1.32	-	1.12	1.15	62
	1.32		1.27	1.18	62
	1.27				
	1.27				
	1.39				
TC 30019	1.30	-	1.45	1.14	65
	1.33	-	1.31	1.21	68
	1.36	-	1.43	1.17	65
	1.37		1.40	1.17	66
	1.35				
	1.35				
	1.34				
TC 30033	1.37	-	1.09	1.19	65
	1.37	-	1.10	1.27	65
	1.34	-	1.25	1.30	67
	1.34		1.15	1.25	66
	1.35				
	1.32				
	1.35				

TABLE 13

MOTOR TC 30005 MATERIAL PROPERTIES DATA
7-YEAR (1985) RESULTS

Sample Area	Mini DPT Maximum Stress (psi)	Mini DPT Failure Mode (%) APL	CL	CLI	Liner Swell Ratio	Liner Gel Fraction	Liner Moisture (%)
Forward Flap	44	20	80		1.82	0.443	Not Required
Segment 1B6	44	40	60		1.88	0.457	
	23	0	100		1.88	0.440	
	29	0	100		1.94	0.337	
	31	0	100		1.94	0.466	
	33	30	70		1.94	0.412	
	34				2.13	0.375	
					2.06	0.374	
					2.13	0.385	
					1.75	0.410	
Barrel, Between Ground Straps	Not Required This Year						
Barrel, Under Ground Straps	Not Required This Year						
Aft Flap	Not Required This Year						

TABLE 14

MOTOR TC 30019 MATERIAL PROPERTIES DATA
7-YEAR (1985) RESULTS

Sample Area	Mini DPT Maximum Stress (psi)	Mini DPT Failure Mode (%) APL	Mini DPT Failure Mode (%) CL	Mini DPT Failure Mode (%) CLI	Liner Swell Ratio	Liner Gel Fraction	Liner Moisture (%)
Forward Flap Segment 1B6	34	0	100	-	2.26	0.413	Not Required
	26	0	100	-	2.19	0.405	
	38	0	100	-	2.26	0.383	
	36	0	100	-	2.11	0.414	
	32	0	100	-	2.06	0.347	
	41	0	100	-	2.08	0.313	
	34				2.25	0.260	
					2.17	0.360	
Barrel, Between Ground Straps	Not Required This Year						
Barrel, Under Ground Straps	Not Required This Year						
Aft Flap	Not Required This Year						

TABLE 15

MOTOR TC 30033 MATERIAL PROPERTIES DATA
7-YEAR (1985) RESULTS

Sample Area	Mini DPT Maximum Stress (psi)	Failure Mode (%) APL	Failure Mode (%) CL	Failure Mode (%) CLI	Liner Swell Ratio	Liner Gel Fraction	Liner Moisture (%)
Forward Flap	35	0	100	-	2.47	0.404	Not Required
Segment 1B6	35	0	100	-	2.47	0.432	
	45	10	90	-	2.11	0.417	
	26	10	90	-	2.16	0.395	
	22	0	100	-	2.00	0.548	
	39	0	100	-	2.05	0.465	
	34				2.21	0.444	
Barrel, Between Ground Straps	Not Required This Year						
Barrel, Under Ground Straps	Not Required This Year						
Aft Flap	Not Required This Year						

TABLE 16

MOTOR TC 30005 LINER PENETROMETER DATA
FORWARD EQUATOR PROFILE, SEGMENT 2L2, 10-SEC READINGS
76°F, 7-YEAR (1985) RESULTS

Distance Aft of Equator (in.)	Penetration (10^{-1} mm) Standard Needle 100g Weight	Standard Needle No Weight	Fine Needle No Weight
-1	68	37	51
1	32	17	22
3	48	29	32
5	62	34	35
7	53	31	31
9	60	33	37
11	76	39	47

TABLE 17

MOTOR TC 30019 LINER PENETROMETER DATA
FORWARD EQUATOR PROFILE, SEGMENT 2L2, 10-SEC READINGS
76°F, 7-YEAR (1985) RESULTS

Distance Aft of Equator (in.)	Penetration (10^{-1} mm) Standard Needle 100g Weight	Standard Needle No Weight	Fine Needle No Weight
-1	42	32	35
1	33	18	21
3	48	22	31
5	47	21	29
7	58	34	41
9	59	34	36
11	68	39	46

TABLE 18

MOTOR TC 30033 LINER PENETROMETER DATA
FORWARD EQUATOR PROFILE, SEGMENT 2L2, 10-SEC READINGS
76°F, 7-YEAR (1985) RESULTS

Distance Aft of Equator (in.)	Penetration (10^{-1} mm) Standard Needle 100g Weight	Standard Needle No Weight	Fine Needle No Weight
-1	48	30	49
1	44	23	24
3	53	30	35
5	59	33	34
7	58	32	38
9	57	27	33
11	68	38	44

TABLE 19

MOTOR TC 30005 STRESS RELAXATION GRADIENT
ANB-3066 PROPELLANT, FORWARD FLAP AREA, AMBIENT
INDIVIDUAL RESULTS, SEGMENT 1B6
7-YEAR (1985) TESTS

Distance From Bondline (in.)	Time From Cutting (hr)	Strain (%)	Relaxation Modulus (psi) Log Time (min) -0.93	-0.34	0.20	0.80	1.30
0.1	2.2	2.00	590	567	477	401	352
	2.3	1.98	769	620	526	448	396
	3.0	2.01	713	561	470	398	349
		2.00	690	583	491	416	366
0.3	2.8	2.00	862	700	596	510	447
	3.2	2.00	944	770	656	562	494
	3.2	2.00	901	723	608	513	451
		2.00	902	731	620	528	464
0.5	3.01	2.00	940	769	659	562	500
	3.8	2.01	978	806	712	609	541
	3.8	1.99	956	780	673	579	531
		2.00	957	785	681	583	524

TABLE 20

MOTOR TC 30019 STRESS RELAXATION GRADIENT
ANB-3066 PROPELLANT, FORWARD FLAP AREA, AMBIENT
INDIVIDUAL RESULTS, SEGMENT 1B6
7-YEAR (1985) TESTS

Distance From Bondline (in.)	Time From Cutting (hr)	Strain (%)	Relaxation Modulus (psi) Log Time (min) -0.93	-0.34	0.20	0.80	1.30
0.1	3.1	2.00	1010	949	685	578	506
	3.1	2.00	902	717	602	502	451
	1.5	-	866	684	578	491	435
		2.00	926	783	622	524	464
0.3	3.7	1.99	1120	915	782	661	591
	3.7	1.98	984	797	679	610	506
	2.1	2.01	1030	841	721	618	549
		2.00	1045	851	727	630	549
0.5	-	-	1150	943	814	697	628
	3.9	2.01	991	814	703	606	540
	2.3	2.02	1060	868	748	645	561
		2.01	1067	875	755	649	575

TABLE 21

MOTOR TC 30033 STRESS RELAXATION GRADIENT
ANB-3066 PROPELLANT, FORWARD FALP AREA, AMBIENT
INDIVIDUAL RESULTS, SEGMENT 1B6
7-YEAR (1985) TESTS

Distance From Bondline (in.)	Time From Cutting (hr)	Strain (%)	Relaxation Modulus (psi) Log Time (min) -0.93	-0.34	0.20	0.80	1.30
0.1	2.0	2.00	708	544	452	379	312
	2.1	1.99	653	503	417	349	306
	2.2	2.01	683	521	427	337	306
		2.00	681	523	432	355	308
0.3	2.2	1.90	844	871	565	474	416
	2.7	1.99	821	667	561	468	421
	2.9	2.00	1110	882	739	624	549
		1.99	925	807	622	522	462
0.5	3.0	1.98	935	762	651	560	489
	3.0	2.02	904	743	565	549	490
	-	2.00	935	738	647	553	491
		2.00	925	748	621	554	490

TABLE 22

PROPELLANT SHORE A HARDNESS, 15-SECOND READINGS
FORWARD EQUATOR AREA, SEGMENT 2L2
7-YEAR (1985) RESULTS

Distance From Bondline (in.)	Motor		
	TC 30005	TC 30019	TC 30033
0.1	66±0.6[1]	61±1.5	62±0.0
0.2	63±1.0	63±1.1	61±1.0
0.3	63±1.0	57±0.6	60±0.6
0.4	64±0.6	56±1.5	59±1.0
0.5	61±1.1	52±0.6	56±1.0
0.6	60±0.6	50±0.6	55±0.6
0.7	57±0.6	50±0.6	54±0.0
0.8	57±0.6	48±0.6	53±0.0
0.9	57±0.0	48±1.0	52±1.0
1.0	57±0.6	48±0.6	53±1.1
1.1	58±0.6	50±0.6	53±1.1
1.2	57±1.0	50±0.6	54±1.1
1.3	56±1.1	52±0.6	53±0.0
1.4	57±1.5	53±1.0	54±0.0
1.5	57±1.0	53±0.6	54±0.6
1.6	57±1.0	53±0.6	54±0.6
1.7	58±0.6	55±0.0	54±1.0
1.8	58±0.6	55±0.6	54±0.6
1.9	59±1.5	54±0.0	55±0.0
2.0	59±1.0	55±0.6	55±0.0

[1]Standard Deviation for Triplicate Tests

TABLE 23

MATRIX FOR SURVEILLANCE TESTING
OF STAGE III MINUTEMAN MOTOR TC 30024

Test Condition	Tests	Test Schedule
Temperature 70 ± 5°F, Humidity 50 ± 5% RH, Motor stored in vertical mode, aft end down	Forward gap measurement[1]	Monthly
	Nipple movement[2]	Monthly
	Aft bore diameter measurement[3]	Monthly
	Radiographic inspection[4]	Every 6 months
	Shore A propellant readings[5]	Every 6 months
	Liner runs (document as required)[6]	Inspection monthly

---

[1]Every 90 degrees

[2]Observed, measured, and documented as required

[3]Measured two places 90 degrees apart

[4]Tangent line bonds, forward and aft separations, x-ray in two modes aft down, forward down

[5]Aft end of motor nozzle well every 60 degrees, 5 places (omit excise sample location at 60 degrees)

[6]Document (photograph) as required. Weigh significant accumulations as required.

TABLE 24

MATERIAL PROPERTIES OF SAT-CONDITIONED MOTOR TC 30050 SEGMENTS: STORE WITH MOTOR TC 30024, TEST AT 2-YEAR INTERVALS

Motor Location	Segment Identification and Test Date	Material	Material Property	Test Conditions[1]	Specimen Type	Number/ Interval
Forward Equator Between Grounding Straps	A2E (1/3) in 1981, A2E (1/3) in 1983, A2E (1/3) in 1985	ANB-3066/ SD-851-2/ V-45	Bond Tensile Profile	0.5 in/min	Mini DPT	12
		SD-851-2	Swell Ratio Profile	--	--	13
			Gel Fraction Profile[2]	--	--	25
Aft Flap	B6C3 in 1981, B6A3 in 1983, B6C4 in 1985	ANB-3066/ SD-851-2/ V-45	Bond Tensile Profile	0.5 in/min	Mini DPT	13
		SD-851-2	Gel Fraction Profile[3]	--	--	14
Barrel Between and Under Grounding Straps	DE3F (1/2) in 1981, DE4B1 in 1983 DE3F (1/2) in 1985	ANB-3066/ SD-851-2/ V-45	Bond Tensile	0.5 in/min	Mini DPT	6
		SD-851-2	Swell Ratio			6
			Gel Fraction[2]			12
Bore Surface	F4B1 in 1981, F4F1 in 1983, F4B2 in 1985	ANB-3066	Uniaxial Tensile[4]	1.0 in/min	Mini Tensile	21
			Shore A[4]	15-Second	--	21

[1]All tests at 77°F, ambient pressure.

[2]Obtain from swell ratio specimens where possible and also from tested mini DPT specimens.

[3]Obtain from tested mini DPT specimens where possible.

[4]Test 3 each at 0.1, 0.2, 0.3, 0.4, 0.5, 1, and 2 in. from bore surface.

TABLE 25

MINI DPT BOND STRENGTH PROFILE OF MOTOR TC 30050 SAT SEGMENTS
AT FIRING OF MOTOR TC 30106 AND 5.5 YEARS LATER

		Maximum Stress (psi)		Failure Mode					
				APL		CL		CLI	
Location	Distance Aft of Forward Equator (in.)	At Firing	5.5 Years Later	A.F.	Later	A.F.	Later	A.F.	Later
Forward	-7	11	-	-	-	100	-	-	-
Equator,	-6	17	16	-	-	100	100	-	-
Between	-5	14	17	-	-	100	100	-	-
Grounding	-4	18	11	-	-	100	100	-	-
Straps	-3	10	14	-	-	100	100	-	-
	-2	7	18	-	-	100	100	-	-
	-1	12	14	-	-	100	100	-	-
	0	37	18	60	-	40	100	-	-
	1	61	34	70	-	-	100	30	-
	2	91	68	80	80	-	20	20	-
	3	86	59	85	80	-	20	15	-
	4	68	50	85	50	-	50	15	-
Barrel,	25 A.F.,	37	14	-	-	100	100	-	-
Between	14 Later	48	16	10	-	90	100	-	-
Grounding		42	22	45	-	45	100	10	-
Straps		42	17						
Barrel,	25 A.F.,	99	83	80	70	-	30	20	-
Under	14 Later	91	85	90	80	-	20	10	-
Grounding		76	85	90	90	-	10	10	-
Straps		89	84						

TABLE 25 (CONTINUED)

MINI DPT BOND STRENGTH PROFILE OF MOTOR TC 30050 SAT SEGMENTS
AT FIRING OF MOTOR TC 30106 AND 5.5 YEARS LATER

Location	Distance Aft of Forward Equator (in.)	Maximum Stress (psi)		Failure Mode					
				APL		CL		CLI	
		At Firing	5.5 Years Later	A.F.	Later	A.F.	Later	A.F.	Later
Aft Flap	-11	-	15	-	-	-	100	-	-
	-10	-	15	-	-	-	100	-	-
	-9	-	19	-	-	-	100	-	-
	-8	-	25	-	-	-	100	-	-
	-7	-	10	-	-	-	100	-	-
	-6	-	7	-	-	-	100	-	-
	-5	-	7	-	-	-	100	-	-
	-3	-	13	-	-	-	100	-	-
	0*	-	-	-	-	-	-	-	-
	2*	-	-	-	-	-	-	-	-
	3*	-	-	-	-	-	-	-	-
	4*	-	-	-	-	-	-	-	-

*Liner too degraded to test.

NOTE: All aft flap sample liner had degraded.

TABLE 26

LINER GEL FRACTION AND SWELL RATIO PROFILES OF MOTOR TC 30050 SAT SEGMENTS AT FIRING OF MOTOR TC 30106 AND 5.5 YEARS LATER

Location	Distance Aft of Forward Equator (in.)	Liner Gel Fraction At Firing	Liner Gel Fraction 5.5 Years Later From Mini DPTs	Liner Gel Fraction 5.5 Years Later From Swell Samples	Liner Swell Ratio At Firing	Liner Swell Ratio 5.5 Years Later
Forward	-6	0.139	0.240	0.184	*	*
Equator,	-5	0.140	0.250	0.185	*	*
Between	-4	0.051	0.234	0.304	*	*
Grounding	-3	0.047	0.229	0.275	*	*
Straps	-2	0.062	0.239	0.291	*	*
	-1	0.127	0.052	0.079	*	*
	0	0.419	0.329	0.299	1.97	*
	1	0.522	0.466	-	1.85	2.08
	2	0.617	0.562	-	1.73	1.88
	3	0.550	0.517	-	1.82	2.08
	4	0.518	0.488	-	1.91	2.18
Barrel,	25 A.F.,	0.222	0.622	0.340	*	*
Between	14 Later	0.257	0.464	0.153		
Grounding		0.251	0.435	0.253		
Straps		0.243	0.507	0.249		
Barrel,	25 A.F.,	0.552	0.597	0.557	1.90	*
Under	14 Later	0.563	0.615	0.469	1.91	
Grounding		0.535	0.608	0.446	1.94	
Straps		0.550	0.607	0.490	1.92	

TABLE 26 (CONTINUED)

LINER GEL FRACTION AND SWELL RATIO PROFILES OF MOTOR TC 30050 SAT SEGMENTS AT FIRING OF MOTOR TC 30106 AND 5.5 YEARS LATER

Location	Distance Aft of Forward Equator (in.)	Liner Gel Fraction At Firing	Liner Gel Fraction 5.5 Years Later From Mini DPTs	Liner Gel Fraction 5.5 Years Later From Swell Samples	Liner Swell Ratio At Firing	Liner Swell Ratio 5.5 Years Later
Aft Flap	-11	-	0.056	*	-	*
	-10	-	0.038		-	
	-9	-	0.044		-	
	-8	-	0.037		-	
	-7	-	0.050		-	
	-6	-	0.035		-	
	-5	-	0.036		-	
	-3	-	0.087		-	
	1	-	0.257		-	
	2	-	0.084		-	
	3	-	0.069		-	
	4	-	0.073		-	
	5	-	0.080		-	

*Liner too degraded to test.

TABLE 27

BORE PROPELLANT MINI TENSILE AND SHORE A GRADIENTS OF MOTOR TC 30050 SAT SEGMENTS AT FIRING OF MOTOR TC 30106 AND 5.5 YEARS LATER

Distance From Bore Surface (in.)	$E^{1.0}$ (psi)		σ_m (psi)		$\epsilon_m^{1.0}$ (%)		$\epsilon_f^{1.0}$ (%)		15-Sec Shore A	
	A.F.	Later	A.F.	Later	A.F.	Later	A.F.	Later	A.F.	Later
0.1	1800±62[1]	1811±528	153±4.0	162±54	17±0.6	14±0.8	20±1.1	20±2.9	71±2.6	67±0.6
0.2	1820±85	1525±217	151±2.3	134±18	15±0.0	14±0.2	19±1.5	20±2.0	74±0.6	68±0.6
0.3	1760±87	1443±423	151±5.1	132±33	15±0.0	15±0.2	18±0.0	20±0.1	73±1.0	67±0.0
0.4	1700±20	1507±77	154±3.5	150±2	15±0.0	15±0.4	18±0.6	18±0.9	72±0.0	68±1.5
0.5	1650±111	1436±73	155±4.0	152±3	15±0.6	15±0.3	19±0.0	19±0.6	72±0.6	66±2.0
1.0	1340±56	878±86	141±3.2	132±3	20±0.0	22±1.3	25±0.6	27±1.5	68±1.0	63±0.6
2.0	1220±15	565±20	134±2.0	110±3	24±0.6	29±0.4	28±3.2	40±2.1	63±0.6	60±0.6

[1]Standard Deviations for Triplicate Tests

TABLE 28

DISSECTED MOTOR TC 30072 SEGMENT TEST DATES

Test Date	Years From Dissection	Forward Nipple	Forward Flap*	Forward Equator	Barrel Between, Under and Bore Surface	Aft Equator*	Aft Flap
1983	Baseline**	1B, 1D, 1F	1D1	2B, 2F, 2J	3B, 3E, 3H	5B, 5E, 5H	6B, 6D, 6F
1984*	1	None	1C2	None	4E	5D	None
1985*	2	1A	1A1	2L	3A	5I	6A
1986*	3	None	1E2	None	4H	5G	None
1987*	4	1C	1C1	2D	3D	5C	6C
1988*	5	None	1B1	None	4B	5A	None
1989*	6	1E	1E1	2H	3G	5F	6E

*Denotes tests not included in Addendum #1

**Except for testing of Forward Flap Segment, baseline testing will be at three locations, namely 60, 180 and 300 degrees.

TABLE 29

MATERIAL PROPERTIES TESTING OF DISSECTED OPERATIONAL MOTOR SEGMENTS

Motor Location	Mini DPT	Liner Gel Fraction	Liner Swell Ratio	Liner C=O/C=C Ratio	Propellant E_r Gradient	Propellant Mini Tensile Gradient	Propellant Shore A Gradient	V-45 E_r	V-45 Moisture	V-45 Plasticizer	V-45 Swell Ratio
Forward Nipple	—	1 Area	—	1 Area	1 Area	—	—	1 Area	1 Area	1 Area	—
Forward Flap	1 Area	1 Area	1 Area	1 Area	1 Area	—	—	1 Area	1 Area	1 Area	1 Area
Forward Equator Between Straps	Profile[1]	Profile[1]	Profile[1]	Profile[1]	3 Areas	—	—	3 Areas[2]	Areas A and C	Areas A and C	Areas A and C
Barrel Between Straps	1 Area[5]	1 Area[5]	1 Area[5]	1 Area[5]	1 Area	—	—	—	1 Area[5]	—	—
Barrel Under Straps	1 Area[5]	1 Area[5]	1 Area[5]	1 Area[5]	1 Area	—	—	—	1 Area[5]	—	—
Bore Surface	—	—	—	—	—	1 Area	1 Area	—	—	—	—
Aft Equator Between Straps	Profile[3]	Profile[3]	Profile[3]	Profile[3]	3 Areas	—	—	3 Areas[2]	Areas A and C	Areas A and C	Areas A and C
Aft Flap	Profile[4]	Profile[4]	Profile[4]	3 Areas	3 Areas	—	—	Area F	Area F	Area F	Area F

[1] At 1-inch intervals from 7 inches forward to 4 inches aft.

[2] Plus hinge bulb gradient.

[3] At 1-inch intervals from 4 inches forward to 7 inches aft.

[4] At 1-inch intervals from tip to 11 inches forward.

[5] Baseline tests at 60-degree location will be a profile at 1-inch intervals from center of grounding strip to center of area between grounding strips.

TABLE 29

MATERIAL PROPERTIES TESTING OF DISSECTED OPERATIONAL MOTOR SEGMENTS

Motor Location	Mini DPT	Liner Gel Fraction	Liner Swell Ratio	Liner C=O/C=C Ratio	Propellant E_r Gradient	Propellant Mini Tensile Gradient	Propellant Shore A Gradient	V-45 E_r	V-45 Moisture	V-45 Plasticizer	V-45 Swell Ratio
Forward Nipple	—	1 Area	—	1 Area	1 Area	—	—	1 Area	1 Area	1 Area	—
Forward Flap	1 Area	1 Area	1 Area	1 Area	1 Area	—	—	1 Area	1 Area	1 Area	1 Area
Forward Equator Between Straps	Profile[1]	Profile[1]	Profile[1]	Profile[1]	3 Areas	—	—	3 Areas[2]	Areas A and C	Areas A and C	Areas A and C
Barrel Between Straps	1 Area[5]	1 Area[5]	1 Area[5]	1 Area[5]	1 Area	—	—	—	1 Area[5]	—	—
Barrel Under Straps	1 Area[5]	1 Area[5]	1 Area[5]	1 Area[5]	1 Area	—	—	—	1 Area[5]	—	—
Bore Surface	—	—	—	—	—	1 Area	1 Area	—	—	—	—
Aft Equator Between Straps	Profile[3]	Profile[3]	Profile[3]	Profile[3]	3 Areas	—	—	3 Areas[2]	Areas A and C	Areas A and C	Areas A and C
Aft Flap	Profile[4]	Profile[4]	Profile[4]	3 Areas	3 Areas	—	—	Area F	Area F	Area F	Area F

[1] At 1-inch intervals from 7 inches forward to 4 inches aft.

[2] Plus hinge bulb gradient.

[3] At 1-inch intervals from 4 inches forward to 7 inches aft.

[4] At 1-inch intervals from tip to 11 inches forward.

[5] Baseline tests at 60-degree location will be a profile at 1-inch intervals from center of grounding strip to center of area between grounding stripe.

TABLE 30

MATERIAL PROPERTY TESTS FOR DISSECTED MOTOR SEGMENTS(1)

Material	Test Type	Conditions	Specimen Type	Number Specimens Profile	Number Specimens Area
ANB-3066/ SD-851-2/ V-45	Bond Tensile	0.002, 0.5, 20 in/min	Mini DPT	36	3
SD-851-2	Gel Fraction	--	--	12	3
	Swell Ratio	--	--	12	3
	C=O/C=C Ratio(2)	--	--	12	1
ANB-3066	Stress Relaxation Gradient (3,4)	2% strain	Mini E_r (0.1x0.5x2 in.)	--	10
	Uniaxial Tensile(3,5)	1 in./min.	Mini Tensile	--	21
	Shore A Gradient(5)	15 sec	--	--	21
V-45	Stress Relaxation (3)	2% strain	Mini E_r (th.x0.5x4 in.)	--	3
	Stress Relaxation Gradient (6)	2%	Mini E_r (0.1x0.5x4 in.)	--	3
	Moisture Content (7)	--	--	12	3
	Plasticizer Content	--	--	--	3
	Swell Ratio	--	--	--	3

(1) All tests at 77°F, 0 psig
(2) By ATR/FTIR using tested mini DPT specimens
(3) Test samples in hoop orientation
(4) Test at 0.1, 0.3, 0.5, 1, and 2 in. from liner interface
(5) Test at 0.1, 0.2, 0.3, 0,4, 0.5, 1 and 2 in. from bore surface
(6) Test near liner interface, in middle of bulb and near split
(7) By Dupont Moisture Analyzer

TABLE [illegible]

MATERIAL PROPERTIES (BASELINE TESTS ONLY)
OF SEGMENTS FROM DISSECTED MOTOR

Material	Test Type	Test Conditions	Specimen Type	Number of Specimens
ANB-3066 Propellant (Bore Area)	Relaxation Modulus	-30^{o}F, 2% strain, 600 psi	4 x 0.5 x 0.5 Tab End	3
	TCLE	0^{o} to 145^{o}F, 0 psi	2 x 0.375 x 0.375	3
	Poisson's Ratio	77^{o}F, 0 psi	4 x 0.75 x 0.75 Tab End	2
	Strain at Maximum Stress	180^{o}F, 0.002 in/min, 0 psi	JANNAF Class B	3
	Strain at Rupture	30^{o}F, 200 in/min, 600 psi	JANNAF Class B	3
V-45/EC2216/V-45 (Tangent Line Area)	Bond Shear Strength	30^{o}F, 20 in/min, 400 psi	Disk Tab End	3

TABLE 32

MOTOR TC 30072 BOND STRENGTH AND LINER PROPERTIES
IN FORWARD NIPPLE AND FORWARD FALP AREAS
2-YEAR (1985) RESULTS

	Mini DPT Bond Strength (psi)					Liner	Liner	Liner C=O/C=C Ratios	
	Rate	σ_m	Failure Mode (%)			Gel	Swell	C=C	C=C
Motor Location	(in./min)	(psi)	APL	CL	CLI	Fraction	Ratio	Stretching	Vinyl
Forward Nipple:									
Segment 1A		Not Required				0.524	Not Required	0.559	0.116
						0.535			
						0.495			
						0.518			
Forward Flap:									
Segment 1A1	0.002	20	-	100	-	0.479	1.89	0.568	0.117
	0.5	45	-	100	-	0.499	1.94		
	20	74	100	-	-	0.436	1.97		
						0.470	1.93		

TABLE 33

MOTOR TC 30072 BOND STRENGTH AND LINER PROPERTIES
IN FORWARD EQUATOR AREA, SEGMENT 2L, BETWEEN GROUNDING STRAPS
2-YEAR (1985) RESULTS

Distance Forward of Forward Equator (in.)	Mini DPT Bond Strength					Liner Gel Fraction	Liner Swell Ratio	Liner C=O/C=C Ratios	
	Rate (in./min)	σ_m (psi)	Failure Mode (%) APL	CL	CLI			C=C Stretching	C=C Vinyl
7	0.002	10	-	100	-	0.445±0.06[1]	2.25±0.0	0.512	0.101
	0.5	30	-	100	-				
	20	73	80	20	-				
6	0.002	15	-	100	-	0.437±0.04	2.31±0.03	0.501	0.101
	0.5	35	-	100	-				
	20	68	-	100	-				
5	0.002	13	-	100	-	0.425±0.03	2.29±0.01	0.519	0.111
	0.5	33	-	100	-				
	20	75	90	10	-				
4	0.002	19	5	95	-	0.561±0.07	2.10±0.01	0.560	0.130
	0.5	34	20	80	-				
	20	77	50	50	-				
3	0.002	23	10	90	-	0.483±0.04	2.24±0.01	0.560	0.118
	0.5	41	60	40	-				
	20	75	100	-	-				
2	0.002	21	40	60	-	0.516±0.02	2.18±0.05	0.587	0.120
	0.5	49	70	30	-				
	20	82	90	10	-				
1	0.002	22	10	90	-	0.476±0.02	2.27±0.12	0.701	0.144
	0.5	40	100	-	-				
	20	73	100	-	-				

[1]Standard Deviation for Triplicate Tests

TABLE 33 (CONTINUED)

MOTOR TC 30072 BOND STRENGTH AND LINER PROPERTIES
IN FORWARD EQUATOR AREA, SEGMENT 2L, BETWEEN GROUNDING STRAPS
2-YEAR (1985) RESULTS

Distance Forward of Forward Equator (in.)	Mini DPT Bond Strength Rate (in./min)	σ_m (psi)	Failure Mode (%) APL	CL	CLI	Liner Gel Fraction	Liner Swell Ratio	Liner C=O/C=C Ratios C=C Stretching	C=C Vinyl
0	0.002	34	100	-	-	0.569±0.03[1]	2.01±0.02	0.734	0.162
	0.5	59	100	-	-				
	20	103	100	-	-				
-1	0.002	42	10	90	-	0.644±0.01	1.88±0.04	0.714	0.188
	0.5	75	100	-	-				
	20	124	100	-	-				
-2	0.002	55	80	20	-	0.710±0.03	1.78±0.02	0.727	0.151
	0.5	79	60	40	-				
	20	129	75	25	-				
-3	0.002	47	10	90	-	0.645±0.03	1.89±0.01	0.729	0.155
	0.5	78	100	-	-				
	20	94	100	-	-				
-4	0.002	38	-	100	-	0.564±0.07	2.00±0.03	0.671	0.127
	0.5	42	100	-	-				
	20	112	100	-	-				

[1]Standard Deviation for Triplicate Tests

TABLE 34

MOTOR TC 30072 BOND STRENGTH AND LINER PROPERTIES
IN BARREL AREA, SEGMENT 2L, BETWEEN AND UNDER GROUNDING STRAPS
2-YEAR (1985) RESULTS

Motor Location	Mini DPT Bond Strength: Rate (in./min)	σ_m (psi)	Failure Mode (%): APL	CL	CLI	CP	Liner Gel Fraction	Liner Swell Ratio	Liner C=O/C=C Ratios: C=C Stretching	C=C Vinyl
Between Grounding Straps, Segment 3A	0.002	50	50	50	-	-	0.586±0.01[1]	1.86±0.02	0.635	0.147
	0.5	66	50	50	-	-				
	20	116	50	50	-	-				
Under Grounding Straps, Segment 3A	0.002	59	50	50	-	-	0.614±0.00	1.72±0.01	0.717	0.138
	0.5	79	50	50	-	-				
	20	148	50	50	-	-				

[1]Standard Deviation for Triplicate Tests.

TABLE 35

MOTOR TC 30072 BOND STRENGTH AND LINER PROPERTIES
IN AFT EQUATOR AREA, SEGMENT 5I, BETWEEN GROUNDING STRAPS
2-YEAR (1985) RESULTS

Distance Aft of Aft Equator (in.)	Mini DPT Bond Strength: Rate (in./min)	σ_m (psi)	Failure Mode (%): APL	CL	CLI	Liner Gel Fraction	Liner Swell Ratio	Liner C=O/C=C Ratios: C=C Stretching	C=C Vinyl
-4	0.002	28	60	40	-	0.453±0.02[1]	2.01±0.02	0.579	0.107
	0.5	54	90	10	-				
	20	69	95	5	-				
-3	0.002	44	60	40	-	0.514±0.02	2.05±0.03	0.420	0.076
	0.5	67	95	5	-				
	20	66	95	5	-				
-2	0.002	52	80	20	-	0.579±0.01	1.80±0.03	0.610	0.130
	0.5	89	90	10	-				
	20	67	95	5	-				
-1	0.002	58	40	60	-	0.601±0.01	1.81±0.03	0.469	0.087
	0.5	98	70	30	-				
	20	70	90	10	-				
0	0.002	39	50	50	-	0.543±0.02	2.00±0.0	0.650	0.120
	0.5	66	90	10	-				
	20	86	90	10	-				
2	0.002	22	75	25	-	0.494±0.01	2.06±0.03	0.549	0.105
	0.5	51	75	25	-				
	20	91	100	-	-				

[1]Standard Deviation for Triplicate Tests

TABLE 36

MOTOR TC 30072 BOND STRENGTH AND LINER PROPERTIES
IN AFT EQUATOR AREA, SEGMENT 5I, BETWEEN GROUNDING STRAPS
2-YEAR (1985) RESULTS

Distance Aft of Aft Equator (in.)	Mini DPT Bond Strength					Liner Gel Fraction	Liner Swell Ratio	Liner C=O/C=C Ratios	
	Rate (in./min)	σ_m (psi)	Failure Mode (%) APL	CL	CLI			C=C Stretching	C=C Vinyl
3	0.002	19	25	75	-	0.417±0.02[1]	2.07±0.03	0.585	0.108
	0.5	40	40	60	-				
	20	87	90	10	-				
4	0.002	16	10	90	-	0.444±0.04	2.09±0.03	0.395	0.073
	0.5	50	75	25	-				
	20	77	95	5	-				
5	0.002	25	70	30	-	0.506±0.02	2.17±0.0	0.564	0.107
	0.5	53	95	5	-				
	20	89	95	5	-				
6	0.002	18	75	25	-	0.424±0.07	2.12±0.03	0.634	0.122
	0.5	58	90	10	-				
	20	79	100	-	-				

Standard Deviation for Triplicate Tests

TABLE 37

MOTOR TC 30072 BOND STRENGTH AND LINER PROPERTIES
IN AFT FLAP AREA, SEGMENT 6A, 2-YEAR (1985) RESULTS

Distance Aft of Aft Equator (in.)	Mini DPT Bond Strength					Liner Gel Fraction	Liner Swell Ratio	Liner C=O/C=C Ratios	
	Rate (in./min)	σ_m (psi)	Failure Mode (%) APL	CL	CLI			C=C Stretching	C=C Vinyl
1	0.002	17	25	25	-	0.447±0.02[1]	2.16±0.03	0.549	0.108
	0.5	30	25	75	-				
	20	42	50	50	-				
3	0.002	19	25	75	-	0.442±0.00	2.20±0.14	Not Required	
	0.5	34	50	50	-				
	20	74	95	5	-				
4	0.002	19	40	60	-	0.538±0.07	2.10±0.0	0.501	0.120
	0.5	33	75	25	-				
	20	58	90	10	-				
5	0.002	21	40	60	-	0.533±0.04	2.10±0.0	Not Required	
	0.5	39	80	20	-				
	20	71	95	5	-				
6	0.002	25	-	50	50	0.511±0.04	2.19±0.05	Not Required	
	0.5	43	90	10	-				
	20	64	100	-	-				
7	0.002	18	-	40	60	0.502±0.03	2.14±0.03	Not Required	
	0.5	43	95	5	-				
	20	66	100	-	-				
8	0.002	29	-	40	60	0.542±0.03	2.08±0.03	Not Required	
	0.5	52	100	-	-				
	20	79	100	-	-				

[1]Standard Deviation for Triplicate Tests

TABLE 37 (CONTINUED)

MOTOR TC 30072 BOND STRENGTH AND LINER PROPERTIES
IN AFT FLAP AREA, SEGMENT 6A, 2-YEAR (1985) RESULTS

Distance Aft of Aft Equator (in.)	Mini DPT Bond Strength					Liner Gel Fraction	Liner Swell Ratio	Liner C=O/C=C Ratios	
	Rate (in./min)	σ_m (psi)	Failure Mode (%)					C=C Stretching	C=C Vinyl
			APL	CL	CLI				
9	0.002	28	90	10	-	0.548±0.01[1]	2.17±0.04	Not Required	
	0.5	56	90	10	-				
	20	74	95	5	-				
10	0.002	30	-	50	50	0.543±0.01	2.11±0.06	0.367	0.073
	0.5	51	90	10	-				
	20	78	100	-	-				
11	0.002	26	-	40	60	0.550±0.04	2.16±0.14	Not Required	
	0.5	51	95	5	-				
	20	73	100	-	-				

[1]Standard Deviation for Triplicate Tests

TABLE 38

MOTOR TC 30072 STRESS RELAXATION GRADIENT OF PROPELLANT
IN FORWARD FLAP AREA, SEGMENT 1A1
2-YEAR (1985) RESULTS

Distance From Bondline (in.)	Time From Cutting (hrs)	Strain (%)	Relaxation Modulus (psi) Log Time (min) -0.93	-0.34	0.20	0.80	1.30
0.1	2.1	2.00	397	302	251	206	177
		2.00	455	349	291	242	212
		2.00	426	326	271	224	194
0.3	2.4	1.99	318	229	184	149	124
	2.8	2.00	323	238	191	156	134
		2.00	320	234	188	152	129
0.5	3.0	2.00	347	259	211	172	147
	3.1	2.00	347	253	208	172	150
		2.00	347	256	210	172	148
1.0	2.6	1.98	330	245	198	161	136
	2.0	2.00	293	218	178	146	135
		1.99	312	232	188	154	136
2.0	3.3	2.00	369	278	227	188	164
	5.0	2.00	358	269	222	184	162
		2.00	364	274	224	186	163

TABLE 39

MOTOR TC 30072 STRESS RELAXATION GRADIENT OF PROPELLANT
IN FORWARD NIPPLE AREA, SEGMENT 1A
2-YEAR (1985) RESULTS

Distance From Bondline (in.)	Time From Cutting (hrs)	Strain (%)	Relaxation Modulus (psi) Log Time (min) -0.93	-0.34	0.20	0.80	1.30
0.1	3.1	2.00	306	235	198	168	148
	3.0	2.00	317	229	184	150	129
		2.00	312	232	191	159	138
0.3	3.4	2.00	330	248	201	163	137
	2.9	1.99	333	246	199	162	137
		2.00	332	247	200	162	137
0.5	3.7	1.99	410	309	256	210	182
	3.4	2.01	376	280	231	187	158
		2.00	393	294	244	198	170
1.0	3.0	2.00	404	305	254	210	182
	3.8	2.00	393	292	243	204	180
		2.00	398	298	248	207	181
2.0	3.3	1.98	268	189	149	118	98
	4.2	2.01	290	207	165	132	111
		2.00	279	198	157	125	104

TABLE 40

MOTOR TC 30072 STRESS RELAXATION GRADIENT OF PROPELLANT
IN FORWARD EQUATOR AREA, SEGMENT 2L
2-YEAR (1985) RESULTS

Motor Location	Distance From Bondline (in.)	Time From Cutting (hrs)	Strain (%)	Relaxation Modulus (psi) Log Time (min) -0.93	-0.34	0.20	0.80	1.30
Area A (Aft of Equator, Between Grounding Straps)	0.1	2.9	2.00	671	545	479	415	372
		4.3	2.00	710	682	527	468	418
			2.00	691	614	503	411	395
	0.3	3.3	-	460	364	317	279	255
		3.7	-	467	382	333	294	266
				463	373	325	286	260
	0.5	3.7	1.99	493	400	346	302	271
			2.01	472	388	337	295	270
			2.00	482	394	341	298	270
	1.0	3.8	1.99	354	241	198	167	149
		4.5	1.99	494	363	306	260	229
			1.99	424	302	252	213	189
	2.0	4.0	2.01	406	317	269	238	212
		4.3	2.00	464	365	320	287	257
			2.00	435	341	294	262	234
Area B (At Equator, Between Grounding Straps)	0.1	4.6	-	586	492	436	383	349
		3.5	-	606	496	433	374	335
				596	494	434	378	342
	0.3	5.0	1.99	443	458	411	368	338
		3.9	2.02	545	362	315	275	247
			2.00	494	410	363	321	292
	0.5	3.5	2.00	439	350	301	260	233
		4.3	2.00	503	426	356	310	280
			2.00	471	388	328	285	256
	1.0	3.8	2.00	295	219	179	147	129
		3.4	2.00	402	339	270	233	208
			2.00	348	279	224	190	168
	2.0	4.2	2.00	342	260	218	184	164
		3.8	2.00	449	351	298	254	226
			2.00	395	305	258	219	194

TABLE 40 (CONTINUED)

MOTOR TC 30072 STRESS RELAXATION GRADIENT OF PROPELLANT
IN FORWARD EQUATOR AREA, SEGMENT 2L
2-YEAR (1985) RESULTS

Motor Location	Distance From Bondline (in.)	Time From Cutting (hrs)	Strain (%)	Relaxation Modulus (psi) Log Time (min) -0.93	-0.34	0.20	0.80	1.30
Area C	0.1	4.1	2.00	374	286	239	202	179
(Forward		2.5	2.00	449	351	297	255	228
of Equator			2.00	411	318	268	228	203
in Flap								
Area)	0.3	3.5	1.99	337	258	414	181	159
		2.8	2.01	354	273	229	194	171
			2.00	345	265	321	187	165
	0.5	3.8	1.99	316	248	208	177	156
		1.9	2.00	362	282	239	204	180
			1.99	339	265	223	190	168
	1.0	4.3	2.00	468	372	318	274	244
		2.3	2.00	455	362	310	266	235
			2.00	461	367	314	270	239
	2.0	2.1	2.00	247	183	152	127	112
		2.7	2.00	310	227	186	154	137
			2.00	278	205	169	140	124

TABLE 41

MOTOR TC 30072 STRESS RELAXATION GRADIENT OF PROPELLANT
IN BARREL AREA, SEGMENT 3A, BETWEEN AND UNDER GROUNDING STRAPS
2-YEAR (1985) RESULTS

Motor Location	Distance From Bondline (in.)	Time From Cutting (hrs)	Strain (%)	Relaxation Modulus (psi) Log Time (min) -0.93	-0.34	0.20	0.80	1.30
Between Grounding Straps	0.1	3.2	2.00	724	633	567	495	437
		4.0	2.00	797	703	609	529	478
			2.00	760	668	588	512	457
	0.3	3.6	2.00	621	516	456	404	366
		2.3	2.00	621	533	460	402	358
			2.00	621	524	458	403	362
	0.5	3.8	1.99	474	375	325	281	252
		2.8	2.00	437	355	312	258	226
			1.99	455	365	318	269	239
	1.0	3.3	2.01	468	351	281	228	177
		2.9	2.00	393	296	249	206	183
			2.00	430	323	265	217	180
	2.0	3.7	-	450	337	278	234	205
		3.5	-	437	324	262	213	179
				443	330	270	223	192
Under Grounding Straps	0.1	3.0	1.99	1360	1170	1040	930	859
		3.9	1.98	1550	1310	1170	1010	899
			1.98	1455	1240	1105	970	879
	0.3	3.3	2.00	924	774	684	608	563
		4.2	2.00	1020	861	752	644	569
			2.00	972	817	718	626	566
	0.5	3.6	1.99	869	748	665	597	536
		2.9	2.01	820	702	628	554	495
			2.00	844	725	646	575	515
	1.0	2.8	2.00	623	506	428	366	319
		3.2	2.00	575	451	389	315	269
			2.00	599	478	408	340	294
	2.0	3.0	2.00	552	433	355	309	273
		3.5	2.00	607	465	384	315	269
			2.00	579	449	375	312	271

TABLE 42

MOTOR TC 30072 STRESS RELAXATION GRADIENT OF PROPELLANT
IN AFT EQUATOR AREA, SEGMENT 5I
2-YEAR (1985) RESULTS

Motor Location	Distance From Bondline (in.)	Time From Cutting (hrs)	Strain (%)	Relaxation Modulus (psi) Log Time (min) -0.93	-0.34	0.20	0.80	1.30
Area A	0.1	3.0	2.00	747	616	540	471	430
(Forward			2.00	790	645	562	496	430
of Equator,			2.00	768	630	551	483	430
Between								
Grounding	0.3	3.4	1.99	731	601	527	445	439
Straps)		3.3	2.00	868	745	638	559	488
			2.00	799	673	582	502	463
	0.5	3.7	2.01	864	726	620	542	487
		3.6	2.00	951	794	696	607	539
			2.00	907	760	658	574	513
	1.0	3.0	1.99	713	563	476	402	354
		3.9	1.99	742	594	483	393	341
			1.99	727	578	479	397	347
	2.0	3.3	2.00	843	681	564	462	396
		3.2	2.00	750	594	514	442	386
			2.00	796	637	539	452	391
Area B	0.1	3.5	2.00	1500	1250	1090	925	816
(At Equator,		4.1	2.00	1350	1110	956	795	683
Between			2.00	1425	1180	1023	860	749
Grounding								
Straps)	0.3	4.0	2.00	1140	927	793	673	598
		3.5	2.00	1270	1260	851	900	592
			2.00	1205	1093	822	786	595
	0.5	3.3	2.00	1460	882	759	637	556
		3.7	2.00	1160	928	773	626	528
			2.00	1310	905	766	631	542
	1.0	3.6	2.00	894	686	554	443	370
		2.4	2.00	1010	794	654	544	463
			2.00	952	740	604	493	416
	2.0	3.9	2.00	912	727	613	527	456
		2.8	2.00	758	633	534	442	375
			2.00	835	680	573	484	415

TABLE 42 (CONTINUED)

MOTOR TC 30072 STRESS RELAXATION GRADIENT OF PROPELLANT
IN AFT EQUATOR AREA, SEGMENT 5I
2-YEAR (1985) RESULTS

Motor Location	Distance From Bondline (in.)	Time From Cutting (hrs)	Strain (%)	Relaxation Modulus (psi) Log Time (min) -0.93	-0.34	0.20	0.80	1.30
Area C	0.1	3.0	2.00	941	757	654	544	478
(Aft of		3.7	2.00	891	677	549	394	351
Equator,			2.00	916	717	601	469	414
in Flap								
Area)	0.3	3.0	1.98	745	606	504	424	365
		4.0	2.00	851	642	519	404	325
			1.99	798	624	511	414	345
	0.5	3.3	2.01	944	749	616	547	475
		2.8	2.00	929	738	627	526	461
			2.00	936	743	623	536	468
	1.0	3.6	2.02	1230	948	759	591	467
		3.1	1.99	2160	951	747	556	423
			2.00	1245	949	753	573	445
	2.0	3.4	2.00	786	607	507	421	350
		3.4	2.00	1030	675	546	445	374
			2.00	908	641	526	433	362

TABLE 43

MOTOR TC 30072 STRESS RELAXATION GRADIENT OF PROPELLANT
IN AFT FLAP AREA, SEGMENT 6A
2-YEAR (1985) RESULTS

Motor Location	Distance From Bondline (in.)	Time From Cutting (hrs)	Strain (%)	Relaxation Modulus (psi) Log Time (min) -0.93	-0.34	0.20	0.80	1.30
Area D (End of Flap Near Nozzle)	0.1	4.3	2.00	475	382	331	280	265
		3.3	2.00	331	254	210	175	158
			2.00	394	318	270	228	212
	0.3	4.2	1.99	492	388	330	283	254
		3.7	2.01	506	404	342	287	272
			2.00	499	396	336	285	263
	0.5	4.6	2.00	528	418	355	303	266
		2.6	2.00	506	404	342	287	272
			2.00	517	411	349	295	269
	1.0	5.3	1.99	506	407	346	292	251
		2.9	2.00	555	444	390	348	326
			1.99					
	2.0	3.0	2.00	497	411	362	318	287
		-	2.00	524	419	362	311	282
			2.00	511	415	362	315	285
Area E (Apex Area)	0.1	3.7	2.00	563	455	392	340	309
			2.00	600	487	410	389	351
			2.00	582	471	401	365	330
	0.3	3.5	2.00	621	500	432	371	296
		2.9	2.00	537	421	355	305	270
			2.00	579	461	394	338	283
	0.5	3.2	2.00	-	-	-	-	-
		3.6	2.00	573	457	392	334	301
			2.00	573	457	392	334	301
	1.0	4.1	2.00	542	433	376	322	289
		4.0	2.00	585	486	426	380	342
			2.00	564	460	401	351	316
	2.0	4.5	2.00	484	395	342	302	275
		3.9	2.00	606	501	441	389	351
			2.00	545	448	392	346	313

TABLE 43 (CONTINUED)

MOTOR TC 30072 STRESS RELAXATION GRADIENT OF PROPELLANT
IN AFT FLAP AREA, SEGMENT 6A
2-YEAR (1985) RESULTS

Motor Location	Distance From Bondline (in.)	Time From Cutting (hrs)	Strain (%)	Relaxation Modulus (psi) Log Time (min) -0.93	-0.34	0.20	0.80	1.30
Area F	0.1	-	2.00	635	534	470	418	370
(Toward		2.9	2.00	-	-	-	-	-
Equator)			2.00	635	534	470	418	370
	0.3	-	2.00	680	639	528	449	398
		2.3	2.00	843	674	584	494	427
			2.00	762	657	556	472	413
	0.5	2.4	1.99	811	665	570	493	438
		2.7	2.01	860	696	614	522	471
			2.00	836	681	592	508	455
	1.0	2.1	2.01	799	658	571	492	439
		3.0	2.00	905	751	650	573	503
			2.00	852	705	611	533	471
	2.0	2.4	2.00	671	559	492	425	380
		2.2	2.00	745	602	526	466	414
			2.00	708	581	509	446	397

TABLE 44

MOTOR TC 30072 STRESS RELAXATION OF V-45 INSULATION
IN FORWARD NIPPLE AND FORWARD AND AFT FLAP AREAS
2-YEAR (1985) RESULTS

Motor Location	Strain (%)	Relaxation Modulus (psi) Log Time (min) -0.34	0.20	0.80	1.30
Forward Nipple					
Segment 1A	2.00	2760	2250	2060	1920
	2.00	2270	2080	1870	1740
	1.99	1990	1830	1660	1550
	2.00	2340	2053	1863	1737
Forward Flap					
Segment 1A1	2.00	2350	2140	1970	1830
	1.98	2320	2120	1950	1820
	2.00	2230	2040	1850	1730
	2.00	2300	2100	1923	1793
Aft Flap					
Segment 6A	2.00	3310	3040	2790	2610
	1.99	3040	2760	2480	2280
	2.00	2540	2350	2180	2040
	2.00	2963	2717	2483	2310

TABLE 45

MOTOR TC 30072 STRESS RELAXATION OF V-45 INSULATION
IN FORWARD AND AFT EQUATOR AREAS BETWEEN GROUNDING STRAPS
2-YEAR (1985) RESULTS

		Relaxation Modulus (psi)			
		Log Time (min)			
Motor Location	Strain (%)	-0.34	0.20	0.80	1.30
Forward Equator:					
Area B	2.00	1080	997	919	866
(Near Case)	2.01	1250	1140	1050	987
	2.00	1280	1180	1100	1030
	2.00	1203	1106	1023	961
Area C	2.00	2410	2210	2030	1860
(Forward of	2.01	2580	2350	2140	2000
Equator, in	2.00	2630	2410	2210	2050
Flap Area)	2.00	2540	2323	2127	1970
Area A	2.01	1480	1340	1200	1100
(Aft of Equator)	2.00	1520	1390	1230	1140
	2.01	1470	1330	1230	1140
	2.01	1490	1353	1220	1127
Aft Equator:					
Segment 5I	2.00	1070	979	900	827
Area B	2.01	1660	1520	1400	1330
	2.00	1320	1260	1150	1020
	2.00	1350	1253	1150	1059
Area C	2.00	2560	2330	2040	1830
(Aft of Equator	2.00	2090	1840	1580	1370
in Flap Area)	2.01	2570	2320	2070	1870
	2.00	2407	2163	1897	1690
Area A	2.00	1470	1340	1220	1150
(Forward of	2.01	1740	1600	1430	1350
Equator)	2.00	1780	1630	1450	1340
	2.00	1663	1523	1367	1280

TABLE 46

MOTOR TC 30072 V-45 INSULATION PROPERTIES IN FORWARD NIPPLE AND AFT AND FORWARD FLAP AREAS 2-YEAR (1985) RESULTS

Motor Location	V-45 Moisture (%)	V-45 DOP (%)	V-45 Swell Ratio
Forward Nipple	1.38	3.30	Not Required
Segment 1A	1.52	-	
	1.66	-	
	1.52	3.30	
Forward Flap	1.24	1.17	1.35
Segment 1A1	1.22	-	1.37
	1.52	-	1.35
	1.33	1.17	1.36
Aft Flap	1.85	1.34	1.33
Segment 6A	1.96	-	1.35
	1.62	-	1.35
	1.81	1.34	1.34

TABLE 47

MOTOR TC 30072 V-45 INSULATION PROPERTIES IN FORWARD AND AFT EQUATOR AREAS BETWEEN GROUNDING STRAPS 2-YEAR (1985) RESULTS

Motor Location	V-45 Moisture (%)	V-45 DOP (%)	V-45 Swell Ratio
Forward Equator			
Segment 2L	1.85	1.53	1.33
Area C (Forward	0.64	-	1.33
of Equator, in	2.33	-	1.33
Flap Area)	1.61	1.53	1.33
Area A (Aft of	1.39	3.11	1.33
Equator, Between	1.49	-	1.37
Grounding Straps)	1.47	-	1.37
	1.45	3.11	1.36
Aft Equator			
Segment 5I	0.96	1.96	1.35
Area C (Aft	1.09	-	1.34
of Equator, in	1.21	-	1.34
Flap Area)	1.08	1.96	1.34
Area A (Forward	1.08	1.78	1.37
of Equator, Between	1.10	-	1.35
Grounding Straps)	1.06	-	1.36
	1.08	1.78	1.36

TABLE 48

MOTOR TC 30072 V-45 INSULATION PROPERTIES IN BARREL AREA BETWEEN AND UNDER GROUNDING STRAPS 2-YEAR (1985) RESULTS

Motor Location	V-45 Moisture (%)	V-45 DOP (%)	V-45 Swell Ratio
Segment 3A, Between Straps	0.91 0.71 0.86 0.83	Not Required	Not Required
Segment 3A, Under Straps	0.86 0.90 0.78 0.83	Not Required	Not Required

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